Progress – the loudspeaker diary

Ever since the new Scanspeak 12M4631G00 came out in the spring of 2002 I thought "I have to do something with this unit!" This will be a "best speaker I have ever built" sort of thing. I have presented this design as a sort of diary, so you can follow my work as I went along. This way you should get a rough idea of how I go about designing and building a speaker.

Concept and design idea's

Building and construction

Designing and tweaking the crossover

Measurements and listening results

Progress – concept and ideas

Cabinet size and shape

A definite trend can be seen in high-end loudspeaker designs recently and that is of the tall slim cabinet. Designs like the Wilson Audio Grand Slamm, Avalon Sentinel, etc are making place for new reference models like the Dynaudio Evidence and Confidence range or the Mission Pilastro. Also taking into account that many people have said "I love the Andromeda but its way too big for me" I decided to go for a tall and slim cabinet. This doesn't automatically mean woofers no bigger than 7" or 8" even if I don't believe in side-firing woofers. These side-firing woofers require steep and low crossovers so that they don't cause weird phase cancellations in the upper-bass / low midrange. I prefer a simple first or second order crossover for smoother integration. The height and depth of the cabinet have no restrictions other than the optimum position for the midrange unit and tweeter and looks.

A separate mid-range unit

As with all types of loudspeaker designs, even a high-end project like this will contain certain compromises – if you choose for one thing then you automatically can't choose for something else. There are a few conditions that must apply for all drivers in this project: Wide frequency response with at least two octaves of cone break-up free output above and below the predicted crossover frequency. This gives the possibility of low order and simple crossover networks. Considering I will be using a series network in which all components interact this condition is fairly high on my priority list. Each driver will also work well with-in its limits, which should contribute to less distortion and greater power handling. A separate mid-range unit has several advantages: Small lightweight cone for "fast" and detailed midrange. In this case 6,5 grams for the Scanspeak 12M4631G00 compared to 20 grams of the Scanspeak 18W8545 often used in 2 or 2,5-way systems as a bass-midrange unit. It sort of bridges the "speed-gap" between a mid-woofer and a tweeter. The magnet and therefore the BL force factor is lower with the 12M4631G00 but more important is the combination of BL and Mms, also known as the acceleration factor, is much better. Here is the calculation and for comparison also that of a well known tweeter:

Scanspeak 18W8545 / Scanspeak 12M4631G00 / Scanspeak D2905-9700

BL=8,0Tm / BL=5,3Tm / BL=3,5Tm

Mms=20grammes / Mms=6,5 grammes / Mms=0,45grammes

Γ=400 / Γ=815 / Γ=7777

The acceleration factor is basically the ratio between the driving force and the moving mass: BL/Mms. The same idea as with a car. A lightweight car with a powerful engine means great acceleration! Because the calculation for BL contains Re of the driver, an 8-ohm driver will have twice the acceleration factor as a 4-ohm unit (considering all else is the same). This is logical as the 8-ohm unit has twice the amount of wire in the air gap on which the force of the magnet can be transferred (considering all else is the same, i.e. voice-coil wire thickness, etc). A pity the 12M4631G00 isn't available as an 8 or 16-ohm unit!

• Small cone for better off-axis response.

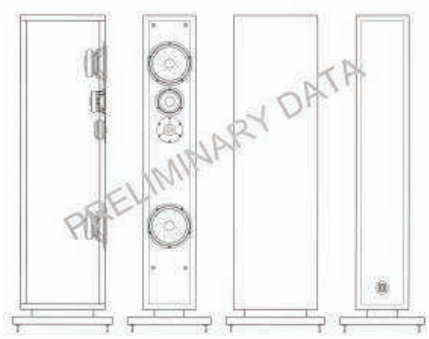
If we take the crossover point fx at 3000Hz for the moment (it may be something else when I start filtering) the 60° off-axis output level of the Scanspeak 12M4631G00 is 3,5dB's down compared to the on-axis response. The Scanspeak 18W8545 is 13,5dB's down at that same point. For a lower fx of 2000Hz the Scanspeak 12M4631G00 is only 1dB down compared to the on-axis response. The Scanspeak 18W8545 is 4dB's down at that point. I believe good smooth off-axis response to be as important as the on-axis response for a stable and wide stereo image (I hate speakers that beam!) and it is also as important for good dynamics. If there is less energy being produced in the frequency range around fx from say 1500-4500Hz compared to the frequencies above and below that (even if it is off-axis energy) this will have an effect on the overall perceived dynamics of the system. I don't have any scientific measurements or so to prove this but I just get this impression from the many speakers I have designed in the past.

• A separate midrange means the mid-woofer can be less "mid" and more "woofer".

This opens up the possibility for a woofer with low fs, slightly heavier cone and therefore better bass response.

30-01-2003

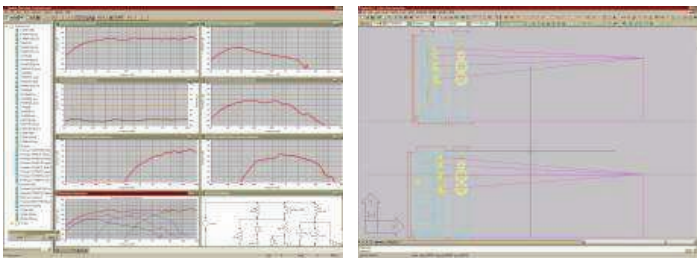
I am a bit late in posting information, been rather busy lately. For the last few months I have been making sketches and calculations to determine the rough size of the cabinet, for looks I want to keep it to about 220x400x1200mm (WxDxH). The main thing that will determine the size of the cabinet is the size and amount of bass drivers. Also I am still investigating the various possibilities of bass loading. Reflex, closed, transmission line or combinations of two types are all open options at this moment.



Here are a few commercial designs which I am looking at for inspiration: The new Dynaudio Contour S5.4; Aerial Model 3 and 5; Sonus Faber Cremona; TAG McLaren F1; leather!

06-02-2003

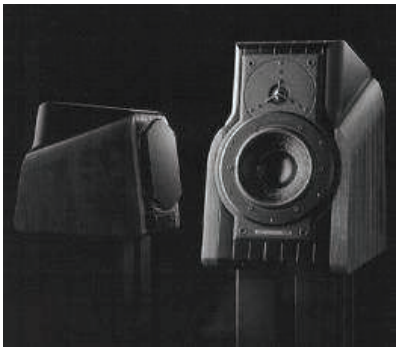
To determine the position of the drivers on the baffle I simultaneously use a CAD programme and crossover design software. By moving the drivers up and down the baffle and backwards or forwards relative to the listening position in the CAD programme I can get a fairly accurate measurement of the distance from each driver to the listening seat. The relative offset is then feed into the crossover design software to account for the acoustic phase shift due to this offset. I want to try and get away with first-order crossovers if possible; the idea being if it will work with 1st order crossovers, it will also work with higher order crossovers, not the other way around.



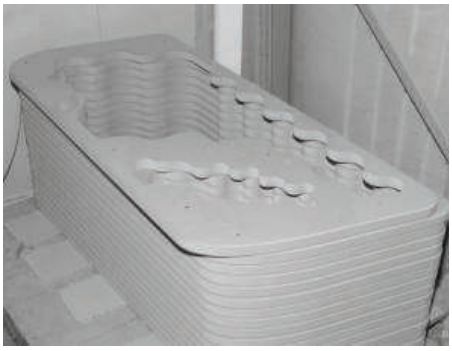
But what ever I tried with the existing preliminary design with its straight baffle (moving the drivers up and down, TMWW, WMTW or other configurations) the only way to get all the drivers into phase was to offset the tweeter and midrange unit several centimetres backwards. This lead me a totally different design: the sloped baffle. Commercial designs that immediately jump to mind are the Thiel CS7, Sonus Faber Grand Piano, Kharma Exquisite, etc. – *(By the way, I used to have double-bass lessons from her bass-player and boy-friend Peter Bjørnild)!* - Sonus Faber just tilts the cabinet backwards by using longer spikes at the front.

Okay next step into cabinet construction. No matter what the speakers will look like, I want a nice strong and dead cabinet that will incorporate the reduction of standing waves inside the enclosure. I could use thick panels, internal bracing, angled internal partitions, etc but I want to take a totally different approach than usual (that's the designer in me wanting to be satisfied). If you look at a vertical cross-section of the cabinet there is a very easy way to combine a sloped baffle and irregular internal shape: the laminated panel technique. This concept has been around for quite a while and can be found in many DIY and commercial designs on the Internet. One of the first companies to exploit it commercially was Sonus Faber with the Extrema launched 12 years ago

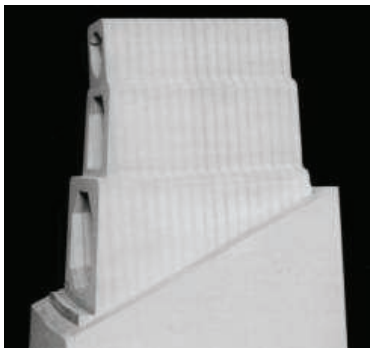
back in 1991.

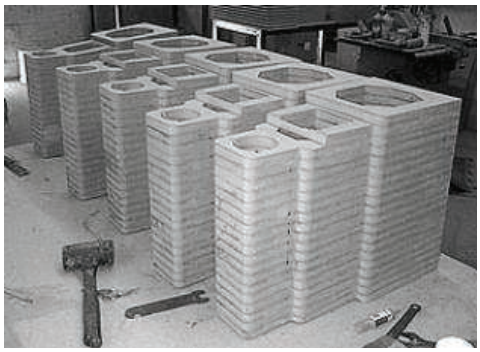


Other designs are the previously mentioned Kharma Exquisite. The Kharma Grand Ceramique uses a similar construction for it upper tweeter/midwoofer section.

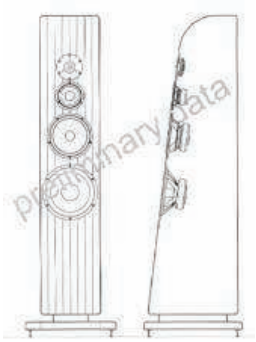


Then there is the Gershman Acoustics Opera Sauvage and the Vandersteen Model 5.



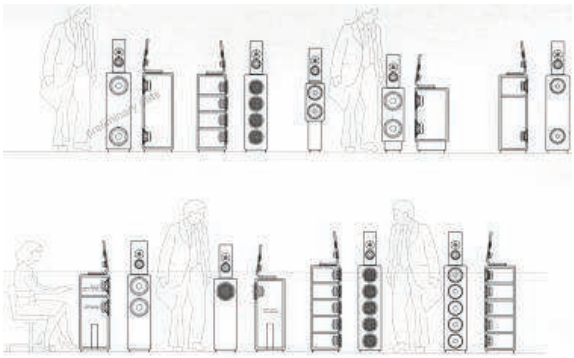


All these ideas lead to the following preliminary design:



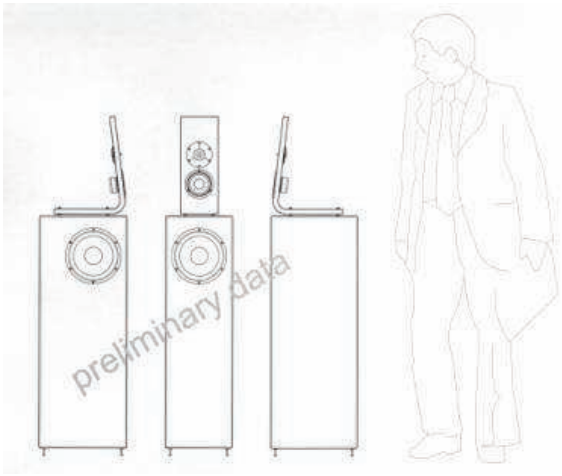
14-02-2003

Still working on different cabinet concepts. The external design should be original (so no Kharma or Thiel type cabinets) and I want to get it down to the bare minimum needed, that means a cabinet (closed and/or reflex) for the woofers; the tweeter only needs something to hold it in place. The midrange unit could be an open-baffle type – if I do this then it will also only need something to hold it in place. This concept opens up new possibilities in cabinet design. The visual aspect of the design must be very pleasing so at the moment I am willing to make minor compromises on the technical side of things if they will lead to significant improvements on the esthetical side. Another interesting consequence is the open baffle midrange, I have read many positive things about this concept and am very curious to try it out. Commercial designs are for example those by Alón. Seeing as the cabinet is becoming more and more final I am also focussing in on the woofers, they will either be 7" or 8" and there will be two per cabinet, so 4 woofers in total.



27-02-2003

The open-baffle-di-pole concept. When the driver is mounted in a rectangular baffle, the wavelength at which bass roll-off commences is equal to the shortest distance between the front and the back of the driver. This is when the distance reaches half a wavelength between front and back. Thus the cone must be at least a quarter wavelength from the edge of the baffle. When L = l/4. For a 15cm wide baffle this would give about 570Hz as the "bending point" of the output curve. Below this point the bass roll-off with 6dB per octave down to fs and then drops with 18dB per octave. This automatically means the woofer must be able to reach well into the midrange without break-up or non-linearity distortion. The advantage of an open baffle is that the many resonances and colourations produced by even a well-designed enclosure are eliminated. The polar propagation of a baffle speaker is that of a doublet, which is a figure eight. Sound pressure at an angle from the front or rear axis is the product of that obtained on-axis and the cosine of the angle. At high frequencies the angle of propagation narrows (as with any speaker) and the rear lobe is distorted by reflection and diffraction caused by the speaker frame and magnet (as with any speaker) – luckily the 12M has a well-designed frame and compact magnet. As frequency increases and the driver becomes more directional of its own, the polar pattern still has an approximately a figure eight shape, because the driver radiates front and rear and little to the sides of the open baffle. The front and rear output will differ because of an acoustic filter formed by the basket openings and trapped air between cone and basket. This filter is the reason for the differences in high frequency response between front and rear. A flat baffle should be operated well clear of any wall otherwise the rear wave is reflected to reinforce and cancel the front wave at quarter and half wavelength spacings and their multiples, respectively. Adding damping material on the rear of the baffle can minimalist this effect.



As you can see the latest design has been taken back to its minimum, I have used the "Golden Ratio" for determining the relation between height, depth and width of both the baffle structure and the woofer cabinet. The Scanspeak R2904-7000 tweeter and the Scanspeak 12M4631G00 midrange unit are mounted on a sort of L-shaped baffle (seen from the side). The original idea was to make the baffle from solid anodised aluminium but that turned out to be too expensive and the aluminium would taper at the bend (ugly). I am now thinking of laminating thin mdf to a total thickness of about 20-25mm. This baffle is fixed to a completely form-follows-function bass cabinet. The front woofer will be running far into the midrange so I want to have it as near to the mid as possible, thats why the tweeter is on top with the midrange unit below. Also phase issues in combination with the shape call for a top mounted tweeter. With the mid at the top the baffle (as seen in some other oopen baffel designs) the baffle would have to slope forwards. For looks the second (sub)woofer is placed in the side of the cabinet, I will worry about phase cancellation later. You may notice that the woofers have grown to 2x 8-inches so that there will be enough cone area for a decent and low bass response. The bass cabinets will be mirror images of each other. At the moment I am leaning towards the new Seas Excel wood-pulp/sisal cone drivers to be used for the woofers – nice looks and a smooth top-end roll-off. Can't wait until Seas publishes the datasheets!

01-04-2003

Okay, I think I have finalised the concept stage! The second (sub)woofer and reflex ports have moved to the bottom of the cabinet. Some commercial speaker manufacturers like Avalon with the Opus also do this down-firing woofer principle for example. They also use a 3-way design with a built-in subwoofer of the same size as the woofer placed in the bottom. This decision has several advantages:

- Less drivers in sight.

A want this speaker not only to sound superb but also to look great. The fewer the amount of visible drivers the better, following

the less-is-more approach. Furthermore "hiding" the subwoofer will strengthen the impression of amazement about the amount of deep bass coming from such a "small" cabinet with only "one" woofer. Driving the second woofer as a subwoofer means it doesn't need to be directly near to the other woofer.

- Greater flexibility in driver choice.

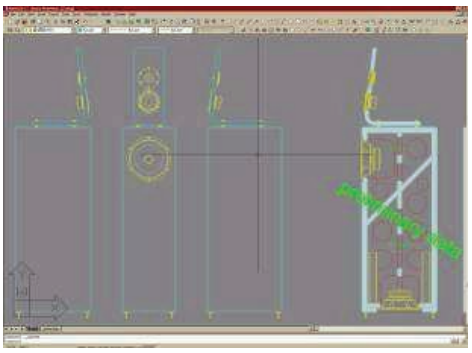
Driving the second woofer as a subwoofer means it doesn't need to have an ultra smooth response in the (upper) midrange because of the simple reason that it won't be working that far up. Even if you filter the peaks out with notch filters there are still sharp phase shifts in that range due to the steep top end cut-off. The opens up the possibilities for metal cone drivers which give great bass detailing but do break-up at the top end of their range.

- Coupling of the air mass to the floor.

Because the subwoofer will only be a few centimetres above the floor, the air "trapped" between the cabinet and the floor on which it is spiked to will be exited by the woofer. This means a larger acoustic source to produce the lowest octaves. Also the boundary reinforcement of the floor will lift the output level of the bass. It should work like a half space radiation more than a semi-free space radiation when a woofer is placed higher up in an enclosure free standing in the listening room.

The ideal woofer for this concept is the new Seas L22RN4X/P. The L22RN4X/P is an 8" cone driver with an extremely stiff and stable injection moulded metal basket. Large windows in the basket both above and below the spider reduce sound reflection, air flow noise and cavity resonance to a minimum. The extremely stiff aluminium cone should give tremendous bass precision. The cone and the low loss rubber surround show no sign of the familiar cone edge resonance and distortion associated with soft cones. On the other hand, the cone break up modes at higher frequencies call for special attention in the crossover design work. A 4-layer, extremely long throw, high temperature voice coil wound on an aluminium voice coil former gives a high power handling capacity. The phase plug reduces compression due to temperature variations in the voice coil, eliminates resonance's that would occur in the volume between the dust cap and the pole piece and increases the power handling capacity. The combination of low fs – 23Hz! – low Vas and a handy Qts give the possibility of deep bass from a small cabinet. Simulations so far predict a –3dB point of about 28Hz from a 35 litre cabinet! Efficiency is correspondingly low but that isn't that much of a problem in this case because they will only be supporting an existing 8" woofer in a 3,5-way set-up.

So to sum things up so far: Scanspeak R2904-7000 ringradiator tweeter; Scanspeak 12M4631G00 sliced non-coated paper midrange, both mounted on an open baffle; Seas Excel W22EX-002 coated sisal wood/paper pulp cone mid-woofer in a closed enclosure (still got to audition these yet); Seas L22RN4XP aluminium cone subwoofer, in a down-firing reflex enclosure.



03-04-2003

Okay, I think I have finalised the concept stage again! – my motto: never be satisfied. The down-firing subwoofer has grown in size to a Seas L26RFX/P and the mid-woofer has shrunk to a Scanspeak 18W8531G00. The reason I changed the subwoofer is because (to quote myself in the Andromeda article): *"I believe that you can only produce "real" bass by moving a large area of air gently and not by moving a small area of air violently. This means that anything smaller than a 10-inch woofer would simply not do".* This statement had been nagging me for a while, so why should I compromise on such a project. Furthermore the Seas L26RFX/P works very well in a closed cabinet. The reason I changed the mid-woofer is two-fold: because the subwoofer has grown in size I would still have enough cone area even if the mid-woofer was slightly smaller. Secondly I wasn't completely happy with the idea of using two different cone materials in the midrange. Seeing as the di-pole midrange unit will have low efficiency in the lower midrange due to cancelation of the front and back waves, the mid-woofer will need to reach relativly far into the midrange to compensate this (there will be a large overlap between the two drivers). Seas Excel coated sisal wood/paper pulp cone was a good compromise, but if I will be using sliced non-coated paper for the mid, why not just stick to sliced non-coated paper for the lower midrange as well?

So to sum things up yet again: Scanspeak R2904-7000 ringradiator tweeter; Scanspeak 12M4631G00 sliced non-coated paper midrange, both mounted on an open time-aligned baffle; Scanspeak 18W8531G00 sliced non-coated paper cone mid-woofer in a closed enclosure; Seas L26RFX/P aluminium cone subwoofer in a down-firing closed enclosure.

NOTE: This design is strictly for the home DIY enthusiast and not to be used professionally without my permission!

Tony Gee, The Netherlands

Progress – construction

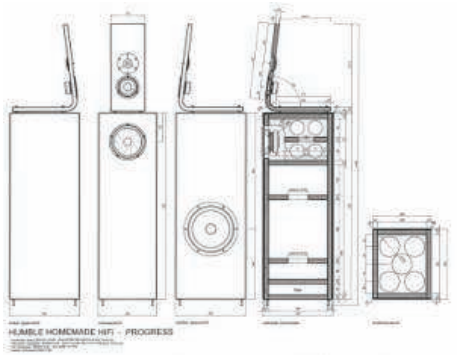
24-04-2003

Well, I've got all the Scanspeak drivers now! I have ordered the Seas sub-woofers; they should arrive in a few weeks. These Scanspeak drivers do look very promising, very well made and they all came in matched pairs. I have plugged the tweeters into my current reference system because I just couldn't wait to try them out. They still need a bit of burn-in time but already I can say they are very, very good! They have a sort of "ease" with the production of the music. Clarity is exceptional without being exaggerated, detailing is good and the efficiency is high (in my current reference system they are running with only a very small series resistor). Furthermore they just look very cool.

A sight for sore eyes!

Regarding the cabinet: I have decided to leave the idea with the laminated panel technique for a later project. If I built the woofer cabinets using this technique then they would either be too large on the outside or the internal volume would be too small. The laminated panel technique is not the most efficient regarding the size / internal volume ratio. So here the compactness of the woofer cabinet won. The final version will use thick panels and internal matrix bracing with circular cut-outs to let the airflow freely in combination with mass loading of the internal walls. The woofer cabinet is constructed from two layers of mdf glued together as I did with the Auriga speaker. Basically it is a 22 mm internal cabinet and all the joints and ends will be finished so that it is nice and smooth. The bottom panel that incorporates the 26 cm sub-woofer is made extra thick and uses a double layer of 22mm mdf (44mm total). The 22mm thick cabinet is covered by a second layer of mdf with a thickness of 6 mm so the total wall thickness adds up to 28 mm. Due to the layered structure with varying density this is much more solid than one single layer of 28 mm mdf. The outer 6 mm mdf is then sanded to make a nice airtight cabinet. Then comes the trick to make the construction look very professional as if all panels were cut to the perfect angle and no panel thickness is visible: cut all edges with an 6 mm facette at a 45 degree angle or rounded off edge (the same as the thickness of the visible layer) using a router. Later on when the cabinets will be spray-painted there will be no small cracks in the paintwork due to the mdf reacting to changes in air humidity or temperature.

The cabinet drawings are finished in a preliminary manner. This means I will be building the cabinets according to this drawing and any alterations made during construction will lead to a final drawing that won't be made until the whole system is finished. So if you can't wait to start building the cabinets then use this drawing, if you don't want to take any risks then wait a few more months for the final version. On the other hand this is a diary so my findings will be published as I go along.



A higher resolution drawing is available on request.

06-06-2003

Well, at last I've got the Seas (sub) woofers! Now I have them in my hands I can get a "feel" about them and how to implement them. They seem to have a relatively soft suspension, which has got me thinking: should I go for the down-fire principle? I have been following several forums on the net about down-fire subs and many mention the woofer cone sagging after a while. I know that is with really heavy coned subs with over 100 grams of moving mass and the Seas L26RFX/P has a moving mass of "only" 58 grams, but still, I have a funny feeling about it. Maybe I will have to go for a side-firing woofer after all. I'll have to think this one

over for a while.



Another sight for sore eyes!

17-06-2003

Should I go for the down-fire principle? That question has been keeping me busy recently. I have checked the Adire Audio "sag" calculator. According to the calculations the Seas L26RFXP would have a sag of 0,63mm which is 9% of Xlin or 3,6% of Xmax. - Yes or No?

Tapio Suonpera from Finland sent me an e-mail with the following interesting and promising information: " I talked about down-fire principle with Mr. Jorma Salmi. He owns Gradient Ltd Finland, which makes some very fine loudspeakers named Gradient Revolution. These loudspeakers are designed by Mr. Salmi and have been praised by The Absolute Sound and Stereophile among the others. He is also the main distributor of SEAS in Finland and has tested them a lot. He said that there would be no sagging problems or changes in parameters when using L26RFX/P in down-fire principle. He has used and measured down-fire elements for over 20 years period and sees no problems with the kind of L26RFX/P. " – Yes!

I also mailed Seas directly and they had the following reply: " We do not recommend to mount the L26 firing downwards since we do not have a long term experience with this driver mounted this way. However, we have many customers that has used our old 25cm units mounted this way without any problems." - Yes or No?

In the past I have built several speakers using Seas 25cm paper and polypropylene cones but all mounted the standard vertical way. Their suspension was stiffer than that of the L26 so I still have some concern about mounting them horizontally. I have built a pair of trial sub-woofers (50 litre closed box) to determine what sounds "better" for my situation. The set-up was very crude but it was only to determine a difference in sonic signature between the down-fire principle and the standard front and side firing principle. The subs were connected parallel to my newly finished Mezzo Proteus speakers with a single high quality 12mH transformer type inductor. To create a height adjustable space between the bottom of the down-fire sub and the floor I placed three large screws per box.



The two sub's next to the Solo-103. Note the height adjustable "spike".

To start off with: I couldn't hear any audible difference between the standard front and side firing principle. Remember, using a 12mH inductor this gives a very crossover frequency so it was obvious that if the woofer were in the front or in the side there wouldn't be much difference. Now for the difference between the down-fire principle and the standard front firing type: The down-firing principle seems to work as a sort of acoustic filter. From the front-firing woofer more lower midrange energy reached the listening spot and muddled up things a bit. The down-fire woofer sounded tighter and only added an extra sense of depth (in image and in bass) to the overall sound without changing any of the existing qualities of the Mezzo Proteus. The front firing woofer tended to "bloat" things up a bit. Note that these statements are made without changing anything to the crossover. To get a similar result from the front-firing woofer it had to go 2nd order with an extra capacitor added parallel. This means a more complex crossover with steeper and deeper swings in the impedance curve, I like to keep things simple where possible, so in this case I preferred the down-fire woofer.

07-08-2003

Its been a while since my last update, but I've been busy lately and not only with these speakers!



As you can see the lower cabinets are ready to go to the paint-sprayer. After all I decided to go for a side-firing sub-woofer, not because of the "sag" problem (I don't think that would have been much of a problem in the end) but because I did some more listening tests and some more simulations and found out that I wanted to have the possibility to let the sub-woofers run a little higher into the bass region than possible with a down-fire woofer. The down-fire sub sounded great when only running up to about 80-100Hz (nice and dry, and strong) but if run any higher it tended to lose its tightness and became a little "thicker". Still very nice bass but not good enough for me!

The photos also show some of the internal matrix construction and a separate open compartment in the bottom where I will be mounting the crossover when it is finished. If you look closely you can see that the edges of the circular matrix cutouts are nicely rounded-off. I don't know if it will make any audible difference but at least it looks cool and was easy and quick to do. And I like to pay attention to every little detail! If you look at the bottom of the cabinet (middle photo) you can see that it is constructed from two layers of mdf glued together – like the Auriga speaker. Basically it's 22mm internal cabinet with a second layer of mdf with a thickness of 6mm so the total wall thickness adds up to 28mm. Due to the layered structure with varying density this is much more solid than one single layer of 28mm mdf. Then comes the trick to make the construction look very professional as if all panels were cut to the perfect angle and no panel thickness is visible: round-off all edges with an 6mm radius (the same as the thickness of the visible layer) using a router. The side panel in which the sub-woofer is mounted is made extra thick and uses a double layer of 22mm mdf (44mm total). Finally you can see the good old trusty carpet-tile lining of the internal panels.

06-10-2003

I've finished the upper section of the cabinet. Its made from 7 layers of laminated finnish birch plywood of 3mm thickness built up to a total thickness of 21mm. The end product has been sprayed RAL 9006 metallic aluminium colour.


03-11-2003

Cabinets completed (except for the correct hieght of the nylon distance rings between the woofer enclosure and the top section). Here is a photo impression:





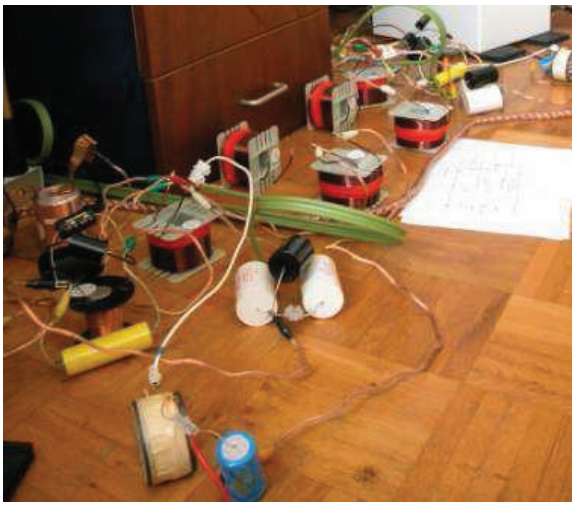


NOTE: This design is strictly for the home DIY enthusiast and not to be used professionally without my permission!

Tony Gee, The Netherlands

Progress – crossover design

30-10-2003 Initial crossover design



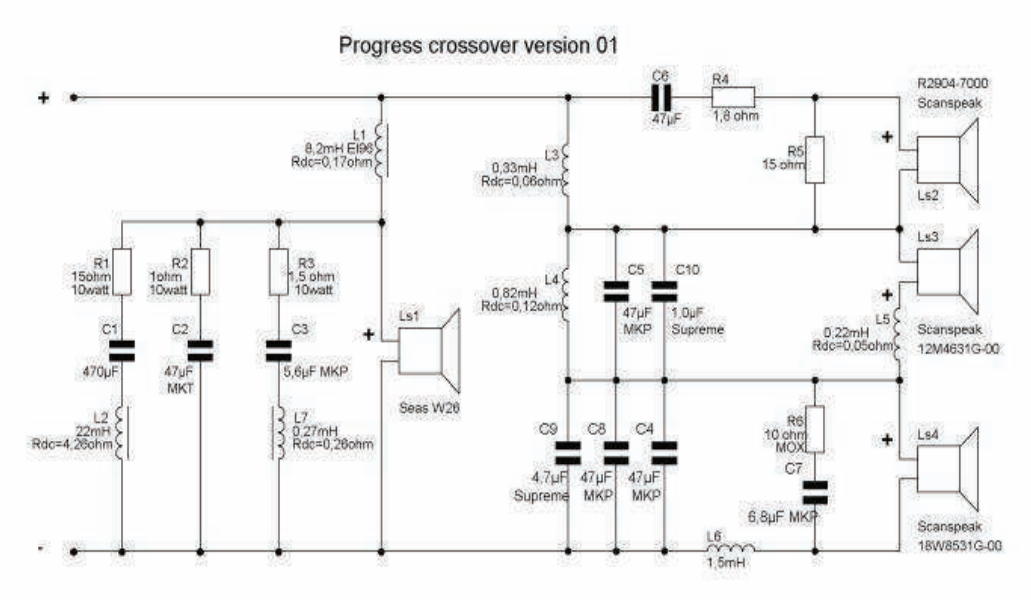
Tweaking the crossover.

The speakers are playing! I put together a crossover based purely on simulations done with frequency curves traced from the official datasheets. These will be different to the ones of the drivers in the actual enclosure but I have found in the past that it can be a good starting point to work from. At least this way it excludes any abnormalities that could occur from measurements later on. Also it forms a reliable data set to compare the real-life measurements with. All drivers are connected in phase except for the midrange unit.

Lets start with the Excel woofer: I decided it would need an LCR to flatten the impedance peak at fc so that the filter function would work properly, an LCR to cut out the cone break-up just above 4kHz and then the actual low pass network being a damped 2^{nd}-order network consisting of 8,2mH and 47uF (the capacitor is damped with a 1 ohm resistor). I wanted the subwoofer section of the crossover to be a separate parallel stage so that it would give the possibility to use an active bass module later on without having to redesign the whole network.

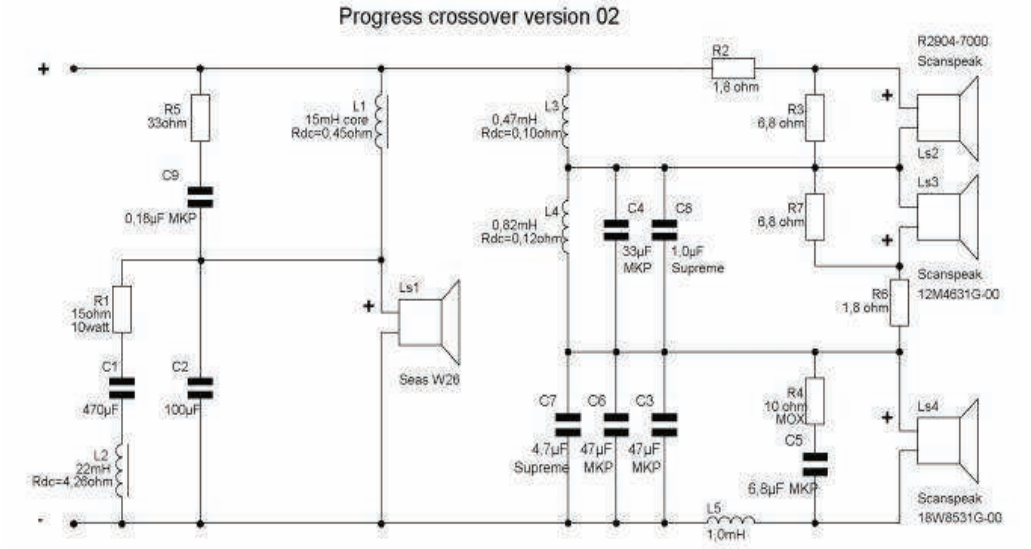
Then we move up to the 3-way series network: A linked series network (the difference between a linked and a cascaded series network can be found on Andy Gradd's site). It is a mix of 1^{st} and 2^{nd} order networks with a Zobel only on the mid-woofer. The tweeter has an L-pad to lower its output level. I added a small inductor in series with the mid-range unit to tailor its top-end response a little.

Sound: not bad but also not good. The overall response is reasonably smooth but it doesn't grip me, nice, but one would expect more from such expensive drivers. Also the balance between everything above 400Hz and everything below 400Hz isn't good. The sims showed a nice well-balanced output level but measurements showed a shelf in the response below 400Hz. Moving the microphone and the speaker around didn't help so it wasn't due to the measurement set-up. Also listening sessions proved an over detailed, over clear and lean sounding speaker. This meant the whole range above 400Hz must be lowered. Spatiality was very good, maybe to do with the open-baffle mid-range.

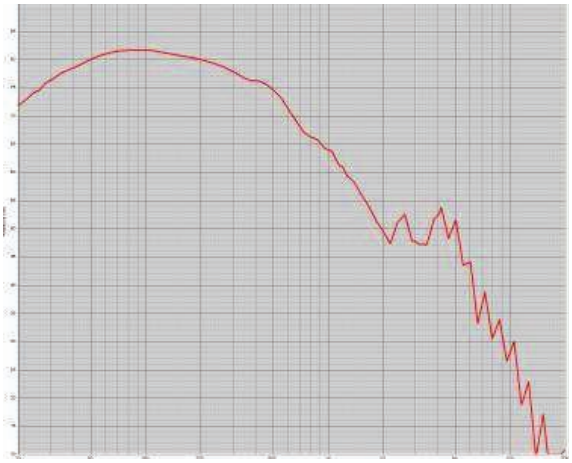


So I lowered the whole range above 400Hz. The resistor parallel to the tweeter is about half going from 15 ohms to 6,8 ohms. An L-pad was added to the midrange drive also consisting of 1,8 and 6,8 ohms. Besides lowering the output level of both drivers the L-pads also form a type of impedance correction networks lowering the peaks at fs and the induction rise due to the voice-coils. I played around a bit with the crossover point between tweeter and midrange changing them both from 2nd order to 1st order. This greatly improved imaging and spatiality. To create a flat response again the mid-woofer needed to run a little higher so its series inductor was lowered from 1,5mH to 1,0mH. The crossover point of the sub-woofer needed to be lowered to stop a bump occurring around the 100-200Hz region, it now has a 2nd order low pass of 15mH and 100uF. Furthermore the LCR to cut out the cone break-up just above 4kHz has been swapped by a CR-network (33 ohms / 0,18uF) parallel to the large inductor. This also cutouts the peak at 4kHz without altering the response above f-peak. A standard LCR-network will just cut-off everything above f-peak. Another small advantage is that is uses one component less and the capacitor is a lot smaller (cheaper). I know this is a cost-no-object project but the principle works for any speaker.

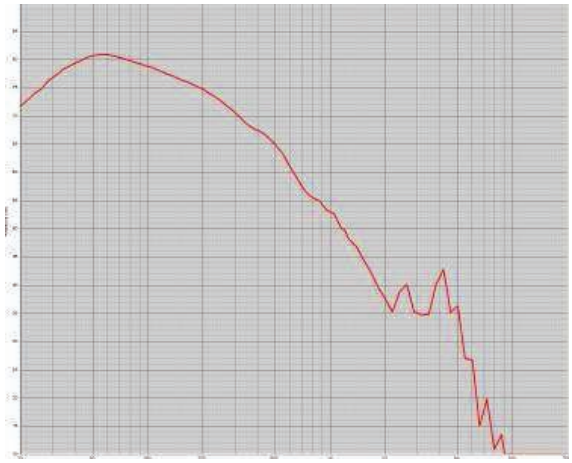
Sound: Overall balance is a lot better, the music now has "body". As stated imaging and spatiality are greatly improved and the midrange is "closer" and "softer", you can hear more into the recording. Bass is deeper and stronger.



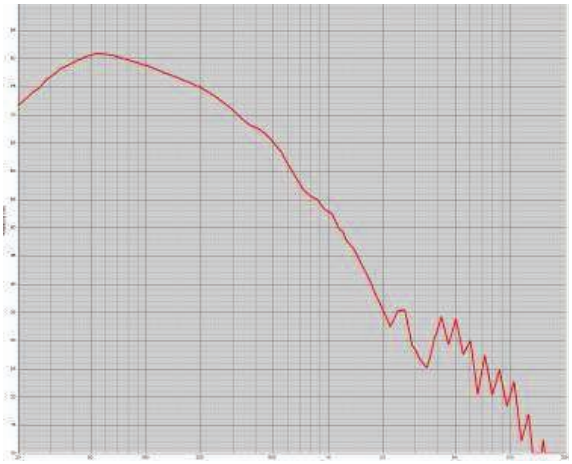
Interested in tuning the bass I looked what effect the sub-woofer network had on the Excel woofers response. All diagrams' horizontal range 20-20.000Hz, vertical range 10-90dB with 5dB divisions.

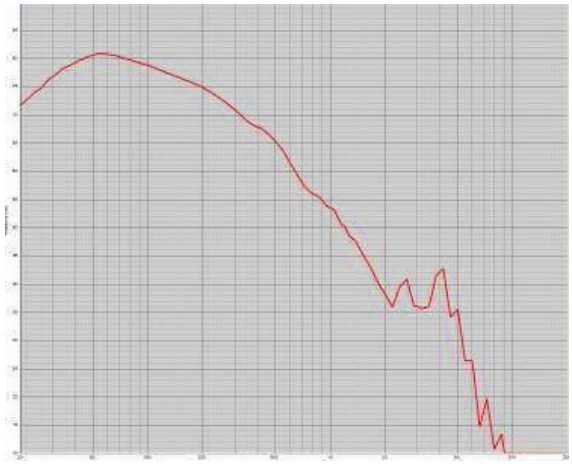


Subwoofer response for crossover version 01.



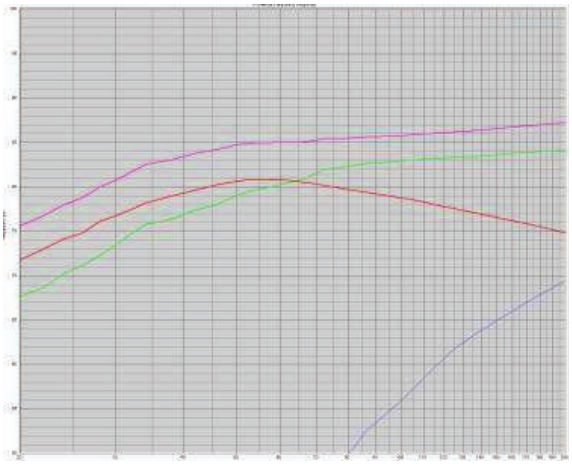
The same but with 15mH / 100uF.

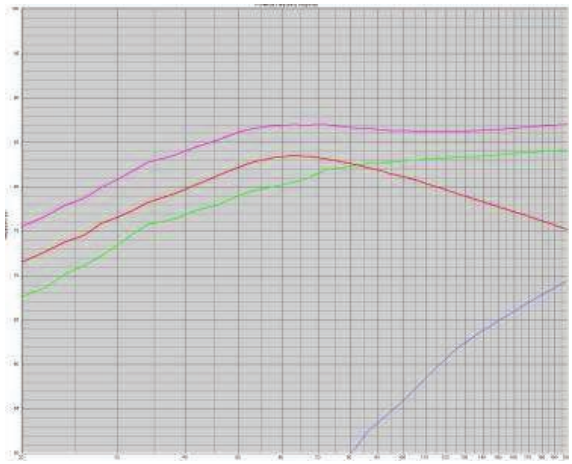




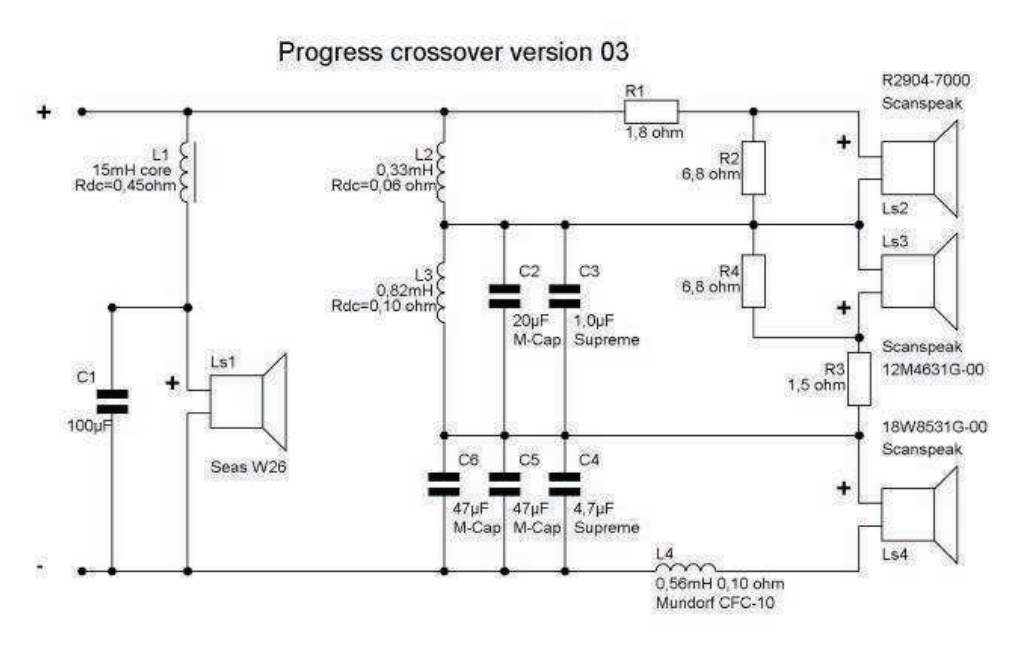
Swapped the LCR for a CR-network. 15mH / 100uF without any network to cut out the cone break-up just above 4kHz.

Seeing as the low-pass function was set at a low 120Hz now the CR-network or LCR network didn't seem much use. So I decided to leave it out. Next step was to give the lowest frequencies a little boost; this can be done by leaving out the LCR (15 ohms / 470uF / 22mH), which flattens the impedance peak at fc. Both diagram's horizontal range 20-200Hz, vertical range 50-100dB with 5dB divisions. Result +2dB's in the 50-70Hz range, this should give a fraction deeper sounding bass, but also there didn't seem much reason to keep the network, so I left it out. The resulting low pass network for the sub-woofer is now just a simple 2nd order network without any corrections.

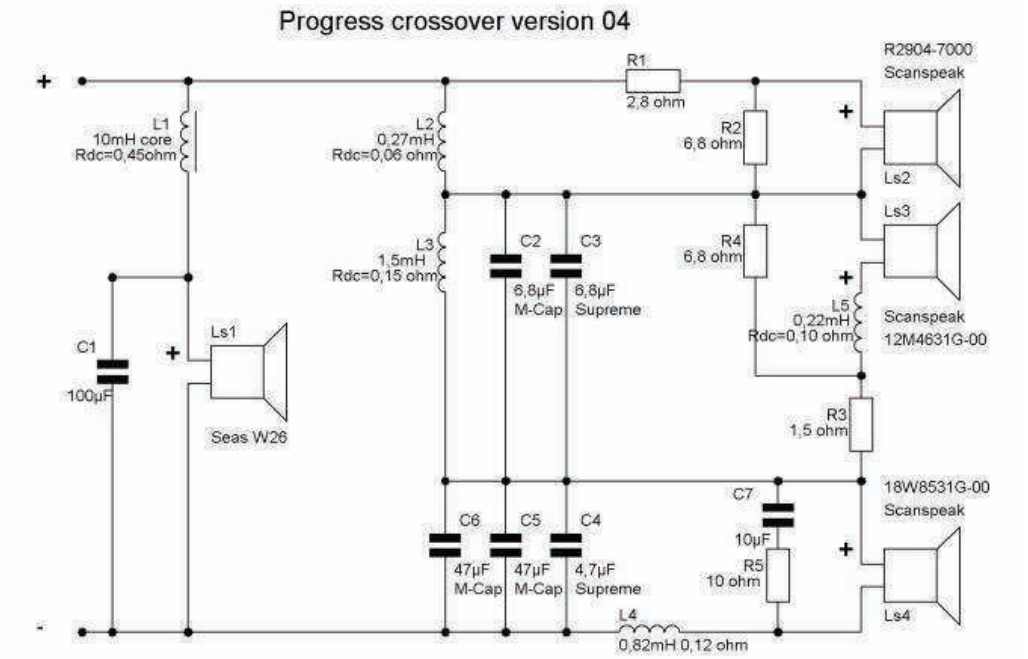




Now I was starting to get somewhere I did the next stage mainly by ear, remember I have ears and a computer doesn't. I felt the midrange could be a little more forward and articulate so I let the 18W8531G-00 run even further by lowering its series inductor to 0,56mH and changing the 12M4631G-00's series resistor to 1,5 ohms. This inductor needs big steps when changing otherwise they are not audible. Stepping up from a 2,5mm wire air-core inductor to a copper-foil version also improved depth and openness a lot; it lowered the noise-floor level even further. I also switched the 33uF M-cap to 20uF so that the tweeter would start a little higher (some recordings were a little to bright and "edgy" otherwise). Interesting also was the Zobel network parallel to the 18W8531G-00, it didn't have any effect on the sound, and so I left it out. I will play around with this crossover concept nr. 03 for a while now, take lots of measurements, do lots of listening and see where it will lead.



18-11-2003 After more listening and measuring

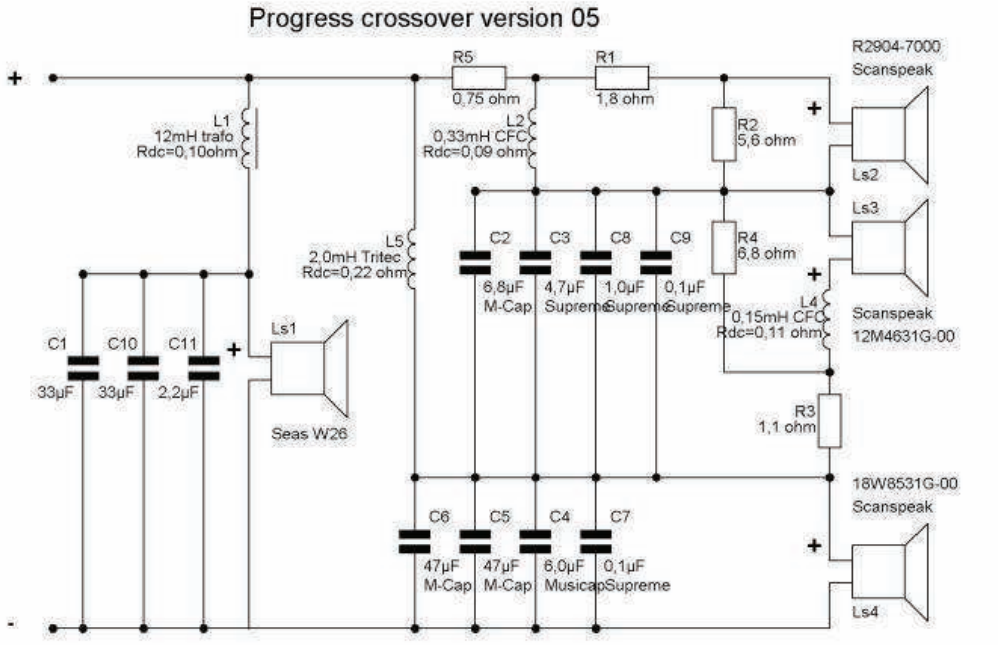


A few more tweaks since my last post. The crossover point between the tweeter and the midrange unit has been moved up slightly adding a little more openness to the midrange and giving the tweeter some extra protection. This meant that the midrange driver needed a little extra taming in its top region so L5 of 0,22mH was added. At the other end the low bass needed more energy so I made L1 a little smaller. The crossover point between the mid-woofer and the midrange unit was altered by changing L3 and L4 and putting back the Zobel for the mid-woofer. The "problem" with a 4 driver 3.5-way system is the large amount of variables. This makes fine tuning the crossover nice and difficult. For example to make the midrange a little more forward I could make L4 smaller or lower the value of R3 or leave out C7/R5 or change L3 to something smaller. All have a more or less same effect on the tonal balance of the whole system. Which one (or combination of) component(s) is the "best" choice? Now just that is the fun of designing speakers for me! This crossover version nr. 04 is already very pleasant to listen to: coherent, open, spacious and smooth. Still I feel there is room for even more improvement – to be continued.

09-01-2004 After even more listening and measuring – the final crossover!

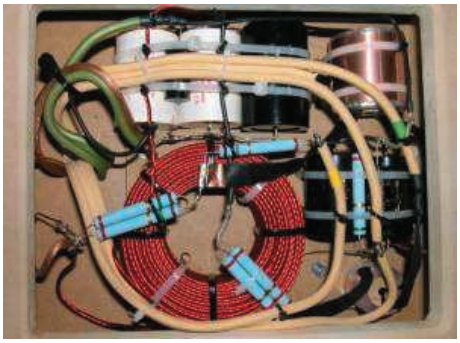
Still tweaking the crossover.

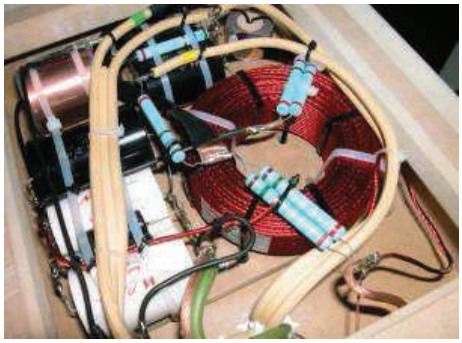
Well it looks that I have finalised the crossover design! In the past few weeks the sub-woofer section has gone from 2nd order to 3rd order and back again. But the real problem was getting the lower midrange balance correct. This speaker is very misleading; the open baffle midrange creates a sound that is totally free of boxiness, which at first gave the impression that I was missing something in the lower midrange. This lead to increasing the overlap between the 18W and the 12M drivers, at one point I was running the 18W nearly full range! This gave more energy in the midrange but the tonal balance was lost; Diana Krall started shouting and Jos van Immerseel's forte-piano sounded like a Casio keyboard. Then I realised what was missing: the overhang created by a cabinet. Compared to the Progress speaker normal speakers sound terribly "boxy" or "cloudy". But even though I didn't need to let the 18W run further (I actually enlarged its series inductor in the end) the speaker still lacked some weight, especially noticeable with the left hand of the piano. Just letting the subwoofer run a little further into the lower midrange wasn't the right way to go, it gave the extra weight but also made the lower midrange less detailed. So I changed the connection of L3 directly to the input of the crossover instead of after the first inductor L2, thus going from a series-linked to a series-cascade model. All things come with a price: the gain in weight came with a compromise in sound stage depth; better tonal balance at the cost of flatter image. Seeing as imaging was still very good I decided that the better tonal balance was more important. Also it gave a new possibility to the crossover: the whole midrange/treble section can now be "dialled-in" with R5 (I ended up with 0,75 ohms made from 2x 1,5 ohms in parallel). This gives extra flexibility when matching this speaker with your equipment and personal taste. The very tricky thing about this speaker is the tweeter and midrange resistors, they have such a great effect on the overall balance of the system and there are 4 of them making the possibilities nearly endless! It's very easy to go wrong here and start changing inductors and capacitors when all you need to do is tweak a resistor or two. R3 by the way is 1,1 ohms made from 2x 2,2 ohms in parallel – this explains how critical the resistors are; the standard 1,0 ohms and 1,2 ohms weren't "it". All the resistor values only work properly in combination with the Rdc of the inductors I used. All resistors are 10 watt MOX.



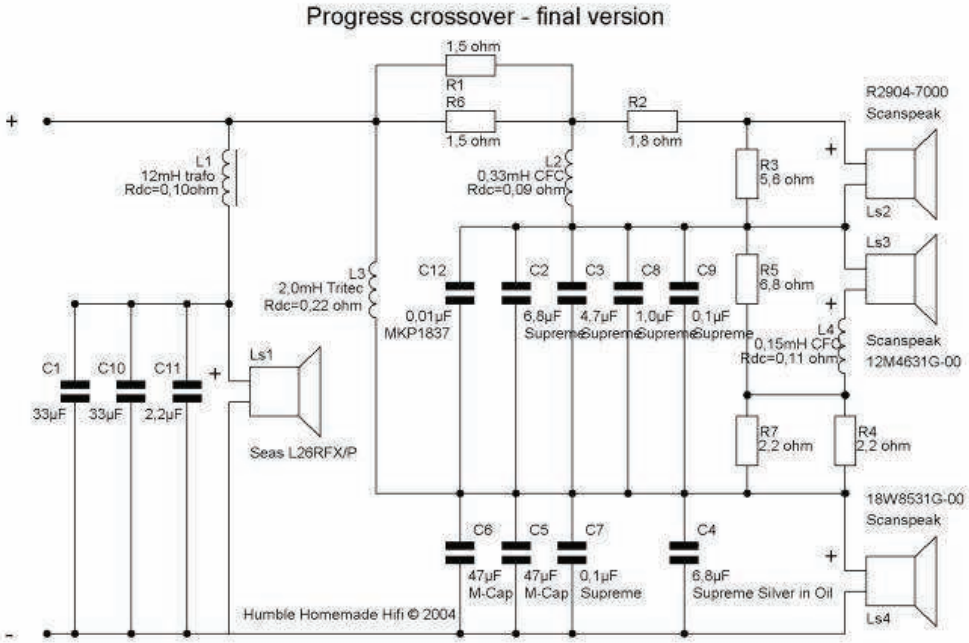
16-01-2004 No more tweaking!

Everything is soldered into place! I made one small but important alteration to the crossover: capacitor C4 (the 6,0uF Hovland Musicap) has been replaced by a 6,8uF Mundorf Supreme Silver in Oil cap. I originally used the Hovland Musicap to "brighten-up" the Mundorf Mcap's a bit. It succeeded in doing this but the "s" sounds in vocals got a nasty edge. The Silver in Oil took away the rough edge and gave overall more depth to the upper range. It would be nice to replace all the capacitors in the series section of the crossover but then I would probably have to sell the house, I presume my wife would object. The photo shows the bottom of the bass cabinet where I made a separate compartment for the crossover. The bass section consisting of the large N-130 transformer and a few cap's are situated inside the bass compartment and therefore not visible on the photo. All components are hard-wired directly to each other. I needed to add only two extra jumper leads and they are made of 2mm solid core copper wire. The cables leading to the drivers are connected directed to the filter components: Green Van Den Hul CS-122 Hybrid for the Scanspeak 18W8531G-00; crème coloured Van Den Hul CS-122 Hybrid for the Scanspeak 12M4631G-00 and the Scanspeak R2904-7000; 4mm^2 OFC copper wire for the Seas L26RFX/P. Note the parallel resistors to get the correct value.





Quite simple for a 3-way crossover!



The final crossover.

L1 = 12 mH Mundorf N130 Zero-Ohm inductor, R = 0,10 ohms

L2 = 0,33 mH copper foil inductor CFC-12, R = 0,09 ohms

L3 = 2,00 mH Tritec inductor 3,50 mm2 wire, R = 0,22 ohms

L4 = 0,15 mH copper foil inductor CFC-16, R = 0,15 ohms

C1 = 33uF MKT polyester foil capacitor

C2 = 6,8uF Mundorf M-Cap Supreme polypropylene foil capacitor

C3 = 4,7uF Mundorf M-Cap Supreme polypropylene foil capacitor

C4 = 6,8uF Mundorf M-Cap Supreme Silver-in-Oil capacitor

C5 = 47uF Mundorf M-Cap polypropylene foil capacitor

C6 = 47uF Mundorf M-Cap polypropylene foil capacitor

C7 = 0,1 uF Mundorf M-Cap Supreme polypropylene foil capacitor

C8 = 1,0uF Mundorf M-Cap Supreme polypropylene foil capacitor

C9 = 0,1uF Mundorf M-Cap Supreme polypropylene foil capacitor

C10 = 33uF MKT polyester foil capacitor

C11 = 2,2uF MKT polyester foil capacitor

C12 = 0,01uF ERO MKP1837 polypropylene foil capacitor

R1 = 1,5 ohms, 10 watts metal film resistor

R2 = 1,8 ohms, 10 watts metal film resistor

R3 = 5,6 ohms, 10 watts metal film resistor

R4 = 2,2 ohms, 10 watts metal film resistor

R5 = 6,8 ohms, 10 watts metal film resistor

R6 = 1,5 ohms, 10 watts metal film resistor

R7 = 2,2 ohms, 10 watts metal film resistor

Ls1 = Seas L26RFX/P – aluminium woofer

Ls2 = Scan speak R2904-7000 – Revelator ring radiator tweeter

Ls3 = Scan speak 12M4631G-00 – Revelator sliced paper mid-range driver

Ls4 = Scan speak 18W8531G-00 – Revelator sliced paper mid-woofer

13-02-2004 Never say no more tweaking!

I tried two more things to bet the maximum possible from these speakers. First of all I wanted to see (hear) what would happen if I added some absorption to the rear waves coming from the open baffle mid-range unit. I used a 10mm thick felt ring, which was placed over the shielded magnet leaving a gap of about 15mm between the felt and the rear of the baffle. The result in sound with the absorber was a little gain in clarity at the cost of dynamics and spatiality, so I decided to leave them out. The second tweak was the addition of a small low voltage capacitor parallel to the tweeter series caps – check out my cap test page for more details.


Without and with the absorber.

NOTE: This design is strictly for the home DIY enthusiast and not to be used professionally without my permission!

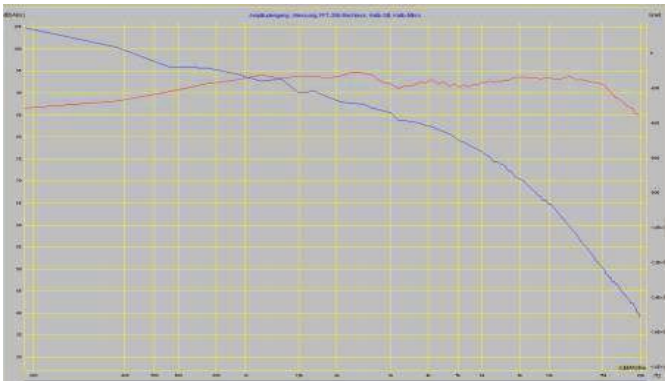
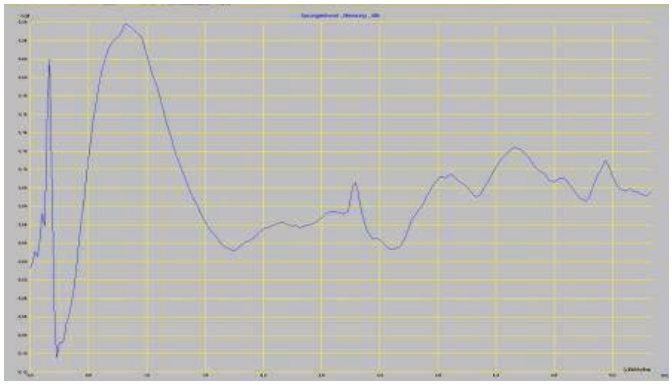
Tony Gee, The Netherlands

Progress – results

The end result

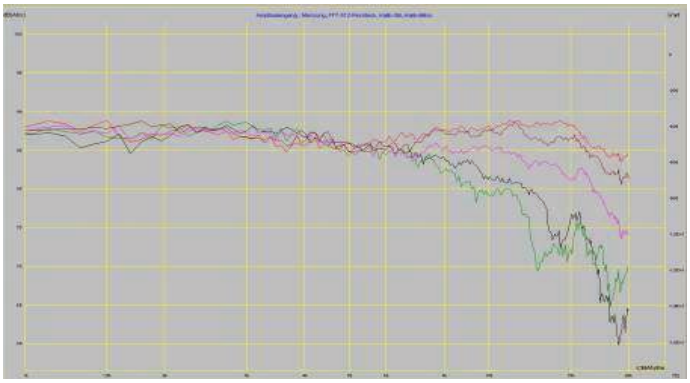


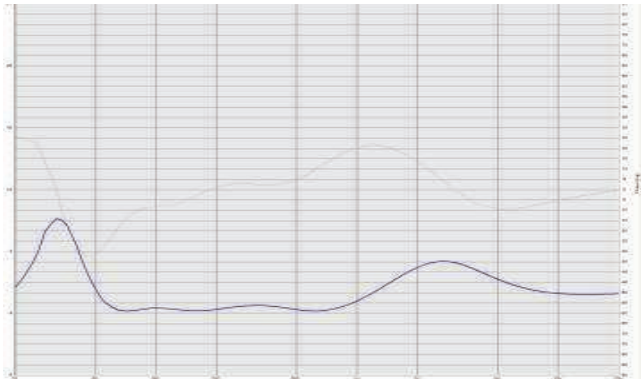

Measurements

1). Output level and acoustic phase 200-20.000Hz – horizontal division 5dB. Smooth response within +/- 2dB, the drop towards the lower end is due to the measurement being done in free-air (so no boundary re-enforcement) – typical in room response is down to about 30Hz. The phase plot is smooth and shows no irregularities. The roll-off above 15kHz is the upper limit of my measuring equipment and not the speaker.

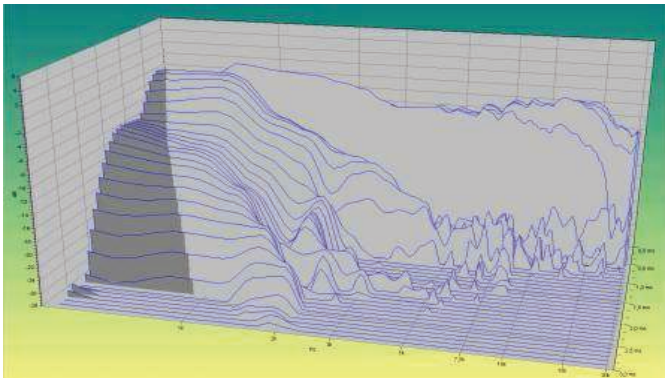
2). Step response – time window 5,0ms. As can be seen from this plot, the tweeter has a fast rise well within 0,2ms it is followed by the midrange driver (connected with reverse polarity), at about 0,4ms – then the midwoofer follows at about 0,8ms.

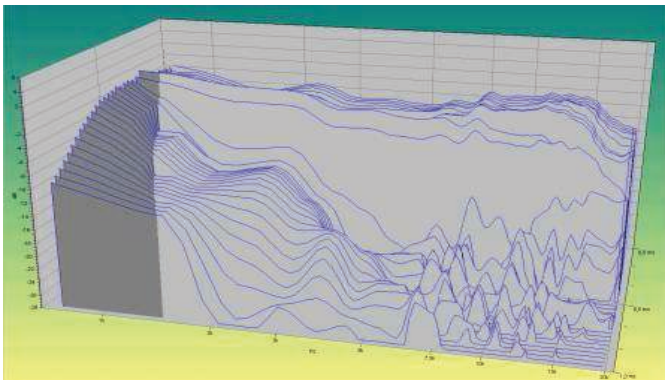




3). Horizontal response 1-20kHz – division 5dB on axis (red) and off-axis 15° (brown) off-axis 30° (purple) off-axis 45° (black) and off-axis 60° (green). The roll-off above 15kHz is the upper limit of my measuring equipment and not the speaker.

4). Impedance curve 20-20.000Hz – horizontal division 1 ohm, scale 0-24 ohms. Electrical phase plot (grey) horizontal division +/- 90°. This looks like an amplifier friendly load.





5). Waterfall plot 400-20.000Hz, time window 3,0ms. Very fast decay of the tweeter.

6). Waterfall plot 800-20.000Hz, time window 1,0ms (zoomed-in on the upper range).

Listening impressions

This must have been one of the most time consuming and expensive loudspeakers I've built, so was it worth all the effort? Well, it produces some of the best midrange and treble I have heard, so open and detailed. Imaging is very good with a well-proportioned depth and width. The speakers are much less critical to placement close to a rear wall than I expected, of course (like with any speaker) imaging is best when there is at least 70cm between the back of the speaker cabinet and the wall, but they can also be placed at only half that distance. The soundstage is a little on the high side (a slightly less tall bass cabinet would have been better) but very realistic in producing the difference between a vocalist sitting and standing. Treble is smooth, detailed and with a transparency leaning towards an electrostatic. Midrange is seamless from top to bottom even though there is a large overlap between the 7" and 4" drivers. The open baffle mid has speed and certain ease to it. The bass is deep, very well controlled but modest. The bass is tuned this way so that it matches the speed and dynamics of the midrange. More bass can be created by changing the series inductor to 10mH or even 8,2mH – but I preferred the 12mH inductor – a definite quality / quantity issue. It would have been nice to give the L26RFX/P more volume to play in but overall cabinet size and looks were an issue here.

NOTE: This design is strictly for the home DIY enthusiast and not to be used professionally without my permission!

Tony Gee,The Netherlands

February 2004