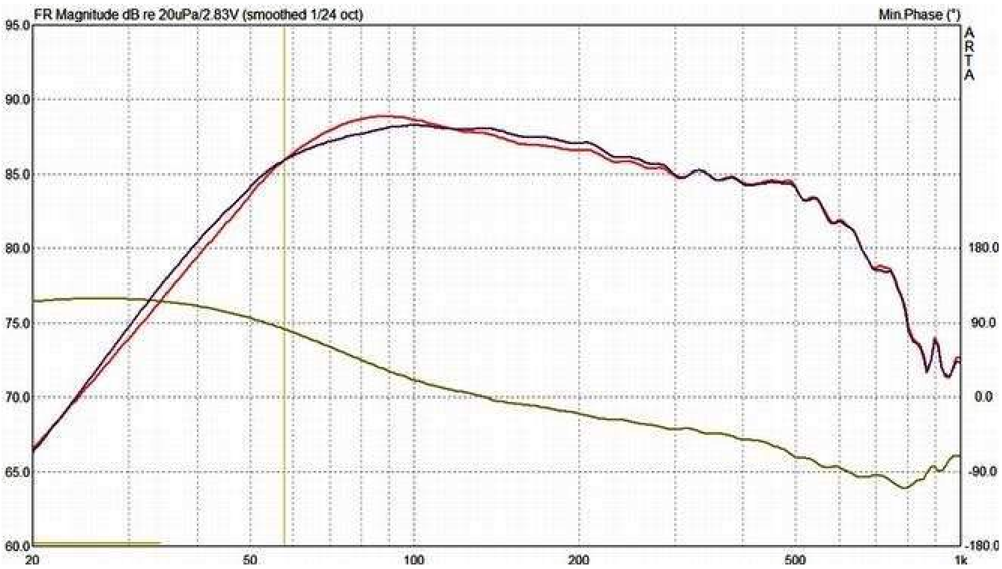
Black Box

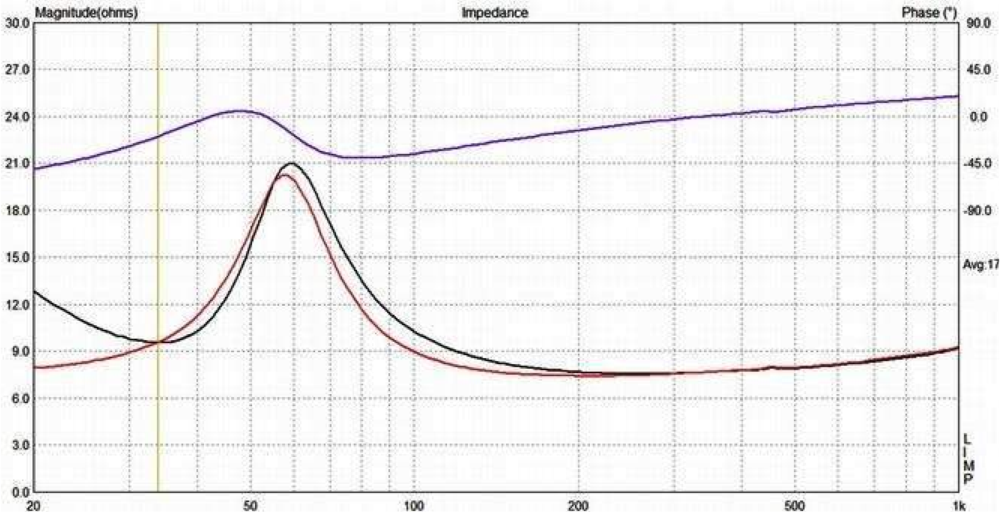
Design Goals

The Black Box was designed to be a precision monitor speaker that could produce deep bass from a relatively small cabinet and have the detail and neutrality of a studio monitor. As I have stated in the past, for me natural effortless bass is only possible with lots of cone area in the low frequency range. When using a single driver, 10 inches is about the smallest size you can get away with. Downside of these large woofers is that they need a lot of air behind them to be able to produce deep bass. This speaker shows you a way to get around that problem and still maintain a full-bodied sound.

The "deep-bass-small-cabinet" concept is based on the principle of mounting a large woofer in a small closed box, purposely creating a slight hump in the output level and then flattening the response by putting a capacitor directly in series with the woofer. When dimensioned correctly, the capacitor will react with the impedance peak of the woofer at resonance. At and just above fc it will raise the impedance, therefore letting less current go to the woofer. Just below fc it will lower the impedance slightly, there drawing a little extra current from the amplifier, thus increasing the output level. So the end result is an enclosure much smaller than the equivalent version without a high-pass capacitor and at the same time having a lower -3dB point in the bass!



This graph shows the filtered response of the woofer in the 24 liter closed cabinet of the Black Box. The red curve is without the woofer series capacitor, the purple cruve shows what happens when a large capacitor is placed directly before the woofer - all other crossover components are unaltered. The bump in the octave from 60-120Hz is lowered and there is a little boost from 120-300Hz resulting in an overall smoother response throughout the whole bass and lower-midrange. Below resonance you can see a gain of about 1dB in the octave 25-50Hz.



This graph shows the impdance of the woofer in the 24 liter closed cabinet of the Black Box. The red curve is without the woofer series capacitor, the black cruve shows what happens when the capacitor is placed directly before the woofer - more current is taken from the amplifier in the octave 25-50Hz, therefore increasing the output level of the woofer. The opposite happens in the range from 55-300Hz. Finally another advantage of this capacitor is that is creates a sub-sonic filter protecting the woofer from infra-sonic frequencies and therefore giving the woofer a little more dynamic headroom and greater power-handling. This can be seen as an impedance rise below 33Hz.

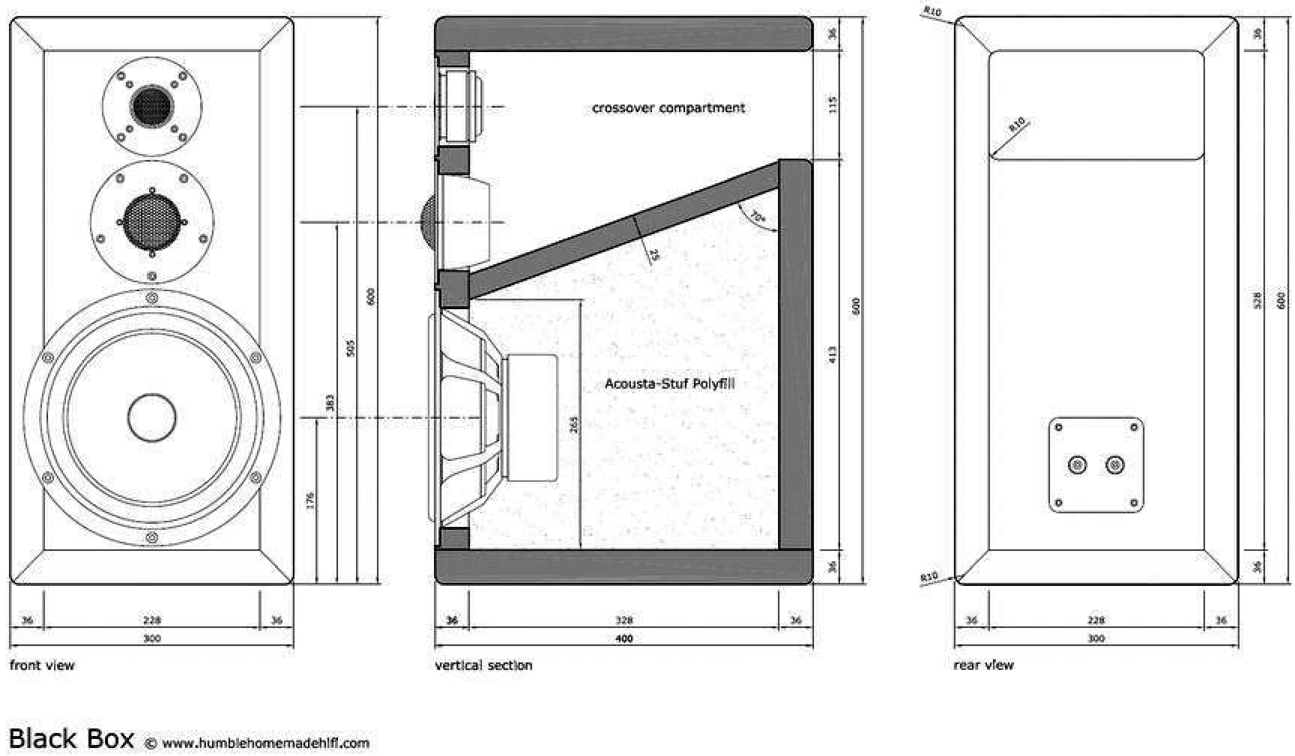
This concept isn't new and to my knowledge has been used in many commercial designs since the late 1970's. Users of this principle (to name just a couple) are Isophon and KEF. Back in the mid 1980's KEF even had several DIY kits available with capacitors in series with the woofer. This Constructor Series CS9 for example had the famous B-300B bextrene woofer with 450uF in it's signal path.

Driver Selection

The only criteria for a woofer to work according to this principle is that the driver must have a low resonance frequency fs (below 30Hz) and a high Q-factor Qts (above 0,40). Basically these type of woofers are designed for use in closed boxes or large bass-reflex enclosures. Browsing around the web, I came across the Dayton RS270S-8. This 10-inch woofer is big enough, has a resonance frequency of 27Hz and a Qts of 0,41. The Q-factor will be raised slightly when there is extra resistance in the signal-path by means of the resistance of connectors and wiring and the Rdc of the inductors, in this case about 0,5 ohms. The Dayton RS270S runs very well up into the midrange, the stiff black anodised aluminium cone showing a very short decay time in the usable area. For a matching pure midrange driver I chose the Dayton RS52AN-8 which is a 2" black anodised aluminium dome-midrange because of it's good on-axis and off-axis radiation pattern. Furthermore the moving mass is much lower than that of a conventional cone midrange, with "speed" and micro-detail in mind, a positive point. The logical tweeter is the Dayton RS28A-4 that also uses a black anodised aluminium dome. I chose a relatively large 1-1/8" tweeter to improve power-handling and maintain a coherent source rather than use a smaller 3/4" dome tweeter that has to be crossed higher and therefore "stretching" the radiation point at high frequencies.

Enclosure Design

Now for the implementation of the woofer/capacitor concept. The cabinet volume for the woofer should be calculated based on a closed box with a Qtc of about 1,0. In this case it results in a nett volume of 24 litres, very small for a 10-inch woofer considering that a standard maximally flat Butterworth alignment with a Qtc of 0,707 would have lead to an enclosure about 3 times as large! The midrange and tweeter come with their own sealed rear volumes so they don't need any extra air from the cabinet. All they need practically speaking is a baffle to be mounted on. The size of the baffle is chosen as compact as possible - the minimum width is determined by the width of the woofer, the minimum height is determined by the space required for mounting the three drivers in a vertical line as close as possible above one another. The spare space behind the midrange and tweeter I reserved for the crossover, kept well away from the high pressure inside the woofer volume. A higher resolution drawing is available on request.



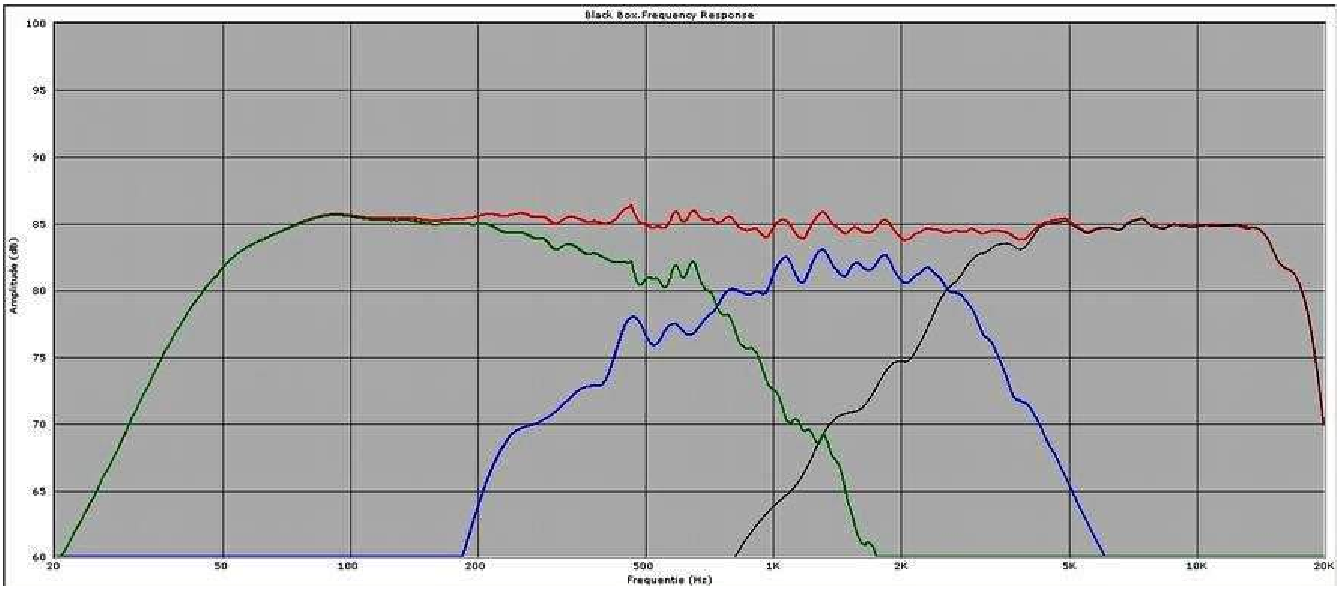
Enclosure Assembly

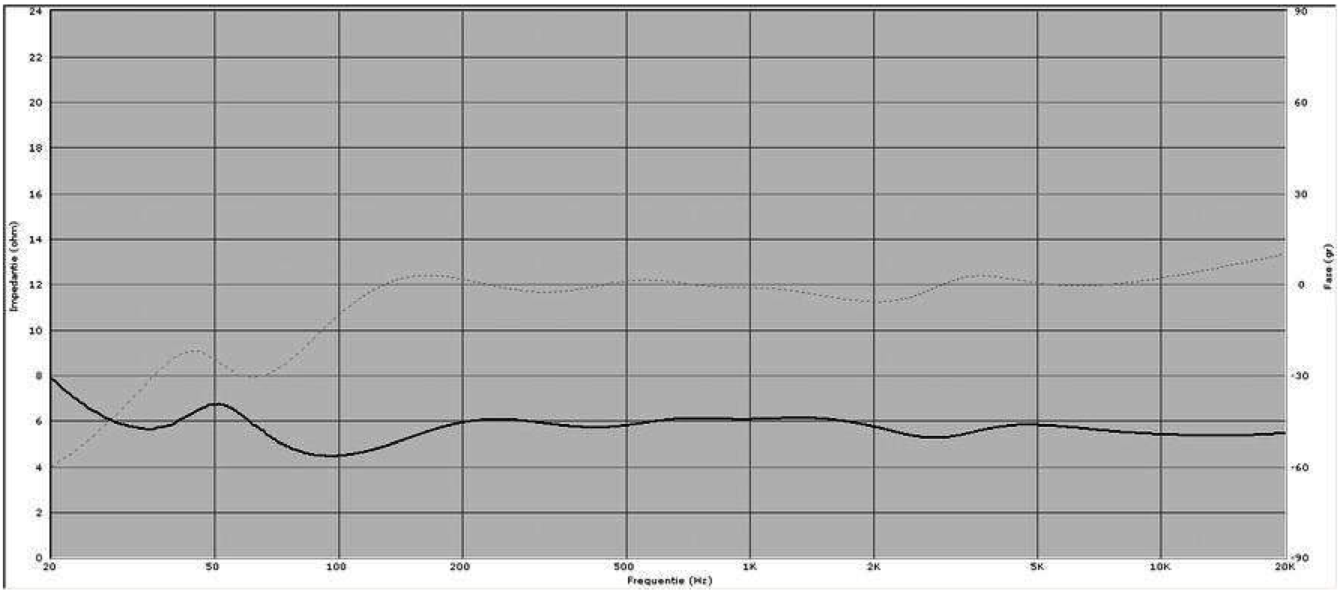
The very solid cabinet is constructed from 36mm mdf with all external edges rounded off with a 10mm radius. Inside there is just one partition separating the woofer volume from the crossover compartment. This crossover compartment is open on the back for easy access. The partition is placed at an angle to minimize standing waves between parallel walls. Damping material consists of a 100% fill of the woofer volume with Acousta-Stuff polyester fibre wool, no further measures are needed. The thick cabinet walls make the loudspeaker very sturdy. All the drivers are recessed in the baffle and on the rear there is a single pair of high-quality binding posts. The cabinets are finished in matt black paint, together with the black anodised cones, domes and face-plates this gives a "Stealth-Like" look to the speakers.

Crossover Design

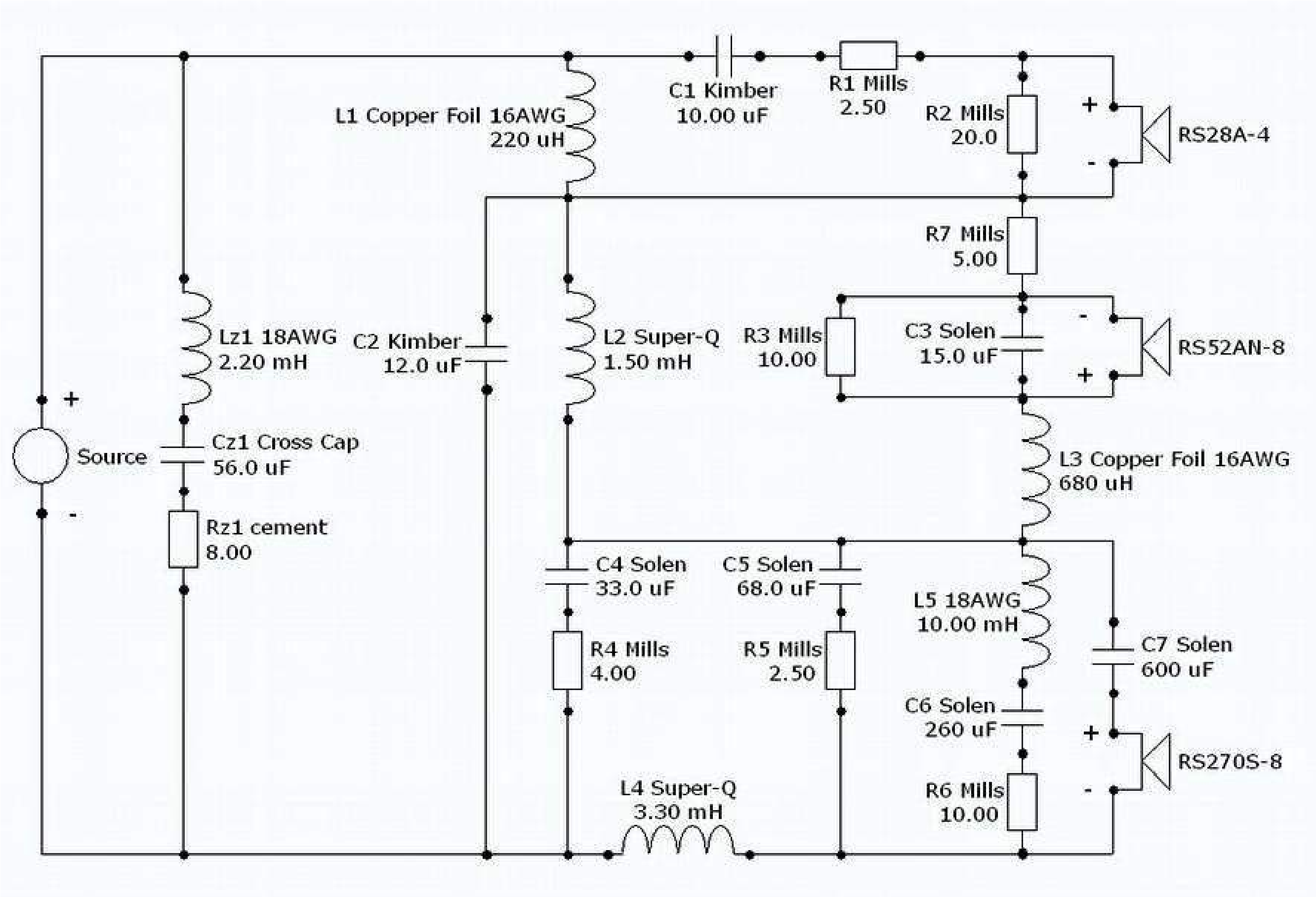
Determining the correct value for the woofer high-pass capacitor is a little fuzzy and besides calculations, involves some empirical determination. The German magazine Hobby-Hi-Fi has done some research the last few years and have come up a simple calculation. The basic formula for working out the rough value of the capacitor is: C=(K x Qts) / (Re x fs). The value of Qts should include all series resistances as mentioned earlier. The value of the constant K depends on the voice-coil inductance. For woofers with a small voice-coil inductance K = 316.000 and for woofers with very large voice-coil inductance, like many sub-woofer drivers, K = 100.000. For standard types like the Dayton RS270S-8 choose K = 265.000. In this situation the formula results in a value of about C = 580uF to 600uF. By fine-tuning the final value of the capacitor one also match the loudspeaker with the room-acoustics. If the capacitor is chosen a little on the small side, say about 10-20% smaller, this will give the loudspeaker a more lean sounding character. This could be ideal for bass-heavy rooms or positioning close to a rear wall.

The remaining components of the filter form a three-way series crossover with modified second-order slopes and a few impedance correction networks thrown in to ensure proper functioning of the network. The result of all these measures is a frequency curve with an efficiency of 85dB/1W/1m that is within +/-0,5dB's over the entire range and a near ruler-flat impedance curve that is centred around a healthy 6 ohms (impedance minimum 4,5 ohms at 95Hz). This should be an easy load for any amplifier. The crossover points are situated at 750Hz and 2500Hz.





The crossover components were chosen for their good price/quality ratio. Nothing exotic with standard quality MKP's through out except for the critical tweeter capacitors C1 and C2. Inductors are standard air-core's where low Rdc is not an issue, laminated-core inductors are used where low Rdc is important. The sound-wise critical midrange inductors L1 and L3 are copper-foil types. All the resistors are induction free types, the couple of extra bucks are worth it here. The amount of midrange can be "dialed-in" to personal taste and system-matching by playing with the value of resistor R3. I found 10 ohms to be ideal in my situation. If you prefer a more forward midrange, then increase the value of R3 to 12, 15 or 18 ohms. If you like the midrange a little lower in level, than decrease the value of R3 to 8,2 ohms or even 6,8 ohms.



Crossover parts list

L1 = 16AWG Copper-foil inductor 0,22mH - Rdc = 0,15 ohms

L3 = 16AWG Copper-foil inductor 0,68mH - Rdc = 0,31 ohms

L5 = 18AWG (1,0mm wire) air-core inductor 10,00mH - Rdc = 1,95 ohms

Lz1 = 18AWG (1,0mm wire) air-core inductor 2,20mH - Rdc = 0,84 ohms

L2 = Erse Super-Q core inductor 1,50mH - Rdc = 0,08 ohms

L4 = Erse Super-Q core inductor 3,30mH - Rdc = 0,13 ohms

C1 = Kimber Cap / Auri-Cap / Jantzen Audio Superior Z-Cap 10uF

C2 = Kimber Cap / Auri-Cap / Jantzen Audio Superior Z-Cap 12uF

C3 = Solen PB-MKP-FC / Mundorf M-Cap / Clarity Cap APW 15uF

C4 = Solen PB-MKP-FC / Mundorf M-Cap / Clarity Cap APW 33uF

C5 = Solen PB-MKP-FC / Mundorf M-Cap / Clarity Cap APW 68uF

C6 = Solen PB-MKP-FC / Mundorf M-Cap / Clarity Cap APW 260uF (100uF + 160uF parallel)

C7 = Solen PA-MKP-FC / Mundorf M-Cap / Clarity Cap APW 600uF (3x 200uF parallel)

Cz1 = Jantzen Cross Cap / Mundorf M-Cap / Clarity Cap APW 56uF

R1 = Mills non-inductive resistor 2,5 ohms / 12 watts (alternative 4x 10 ohms parallel)

R2 = Mills non-inductive resistor 20 ohms / 12 watts (alternative 2x 39 ohms parallel)

R3 = Mills non-inductive resistor 10 ohms / 12 watts

R4 = Mills non-inductive resistor 4 ohms / 12 watts (alternative 5,6 + 15 ohms parallel)

R5 = Mills non-inductive resistor 2,5 ohms / 12 watts (alternative 4x 10 ohms parallel)

R6 = Mills non-inductive resistor 10 ohms / 12 watts

R7 = Mills non-inductive resistor 5 ohms / 12 watts (alternative 3x 15 ohms parallel)

Rz1 = Wire wound resistor 8 ohms / 20 watts (alternative 10 + 39 ohms parallel)

Conclusion

These speakers are best placed on sturdy stands with a bit of space around them. Image size is at its best when the speaker are tilted back slightly, about 5 degrees and the centre between the tweeter and midrange is about at ear-height. The end result of the driver choice, cabinet construction and well thought out crossover design and components, is a very neutral sounding loudspeaker with full-bodied bass, a detailed and coherent image and seamless from top to bottom. The amount of detail at all frequencies lets you listen deep into the recording and at the same time these speakers are not at all over-etched. They combine warmth with detail. The woofer high-pass capacitor concept has proven to be a useful means of combining a large woofer with a small enclosure volume without sacrificing deep bass.

Tony Gee, The Netherlands, November 2009