The AOS Studio 24 BE loudspeaker – some tests, modifications, and extensions

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1. OVERVIEW

The AOS Studio 24 BE (S24) is a closed box MTM loudspeaker. The S24 is sold as a kit by Axel Oberhage Starnberg (AOS) in Germany. The original AOS design is a "bookshelf" format box. However, free-standing operation of the S24 on a stand is acoustically better than stowing it away in a bookshelf. The S24 uses high-quality driver units made by ScanSpeak.

A unique feature of the S24 is that the midwoofers protrude by 18 mm from the front baffle, whereas the tweeter sits flush with the baffle. Most speaker designs lack this offset, which, due to the recessed midwoofer cone(s), causes a lag of the sound wave(s) emitted by the midwoofers relative to that of the tweeter. The additional offset used in the S24 therefore avoids the typical misalignment of the different drivers and therefore allows time-coherent sound emission from the midwoofers and the tweeter.

I decided to modify the original AOS design a little when I built my S24[1]. In particular, I used a full-height floor-standing enclosure for the S24, revised the crossover filters a bit, and added an active subwoofer. The following is a description of how I implemented these modifications in my S24. All measurements shown here were made using MATAA [1] following standard methods [2].

2. DRIVER UNITS

The ScanSpeak Revelator midwoofers 15W9531G01 are a custom model produced for AOS only. The 15W9531G01 is very similar to the standard model 15W8531K00 with low-loss linear suspension, symmetrical drive (SD-1) motor, and sliced paper cone membrane. The slices are filled with a rubbery dampening material, which prevents cone break up. The 15W9531G01 has a slightly higher electrical impedance, and the paper cone is reinforced with wood fibres.

The ScanSpeak Illuminator tweeter D3004/664000 uses a 26 mm beryllium dome. It has a large roll surround which allows very large excursion of up to ±1.6 mm. The motor system uses neodymium magnets and ScanSpeak's AirCir technology.

[1] See http://audioroot.net/aos-studio-24

3. ENCLOSURE

I never really understood the reason for building speakers in the "bookshelf" format, if they are not intended for operation in a bookshelf. For free-standing speakers I prefer full-height, floor-standing enclosures because they allow larger volumes for the bass drivers – and I think they look better. Therefore, I changed the enclosure design for my S24 to a floor-standing speaker (Fig. 1). I made sure to leave the width of the front baffle the the positioning of the drivers on the baffle unchanged.

4. CROSSOVER FILTERS

4.1. Original AOS passive crossover filter. The S24 crossover filter designed by AOS is a passive filter, which consists of clean and simple first-order (6 dB/octave) filters for both the midwoofers and the tweeter (Fig. 2). To make the filters work well, impedance linearisation networks are inserted between the filters and the drivers.

Low pass filter parts:

- L1: 1.5 mH (0.33 Ω, Mundorf CFC14 air core)
- C1: 5.6 µF (MKP)
- R1: 3.9 Ω

High pass filter parts:

- C2: 5.6 µF (MKP, Mundorf Supreme Silver/Gold)
- R2: 3.3 Ω
- L2: 1.0 mH (air core, 1.16 Ω)
- C3: 76 µF (68 µF electrolytic + 10 µF MKP)
- R3: 3.9 Ω

Fig. 3 shows the impedance curves of the midwoofers in the box, with and without the impedance linearisation network. The linearisation network nicely removes the impedance rise kicking in at about 2 kHz, which results in an almost constant (4.5 Ω to 5.5 Ω) impedance in the frequency range above 200 Hz. The low frequency impedance peak reflects the in-box driver resonance with a resonance frequency of f_b = 55 Hz and Q_b = 0.78.

Fig. 4 shows the impedance curves of the tweeter with and without the impedance linearisation network. The

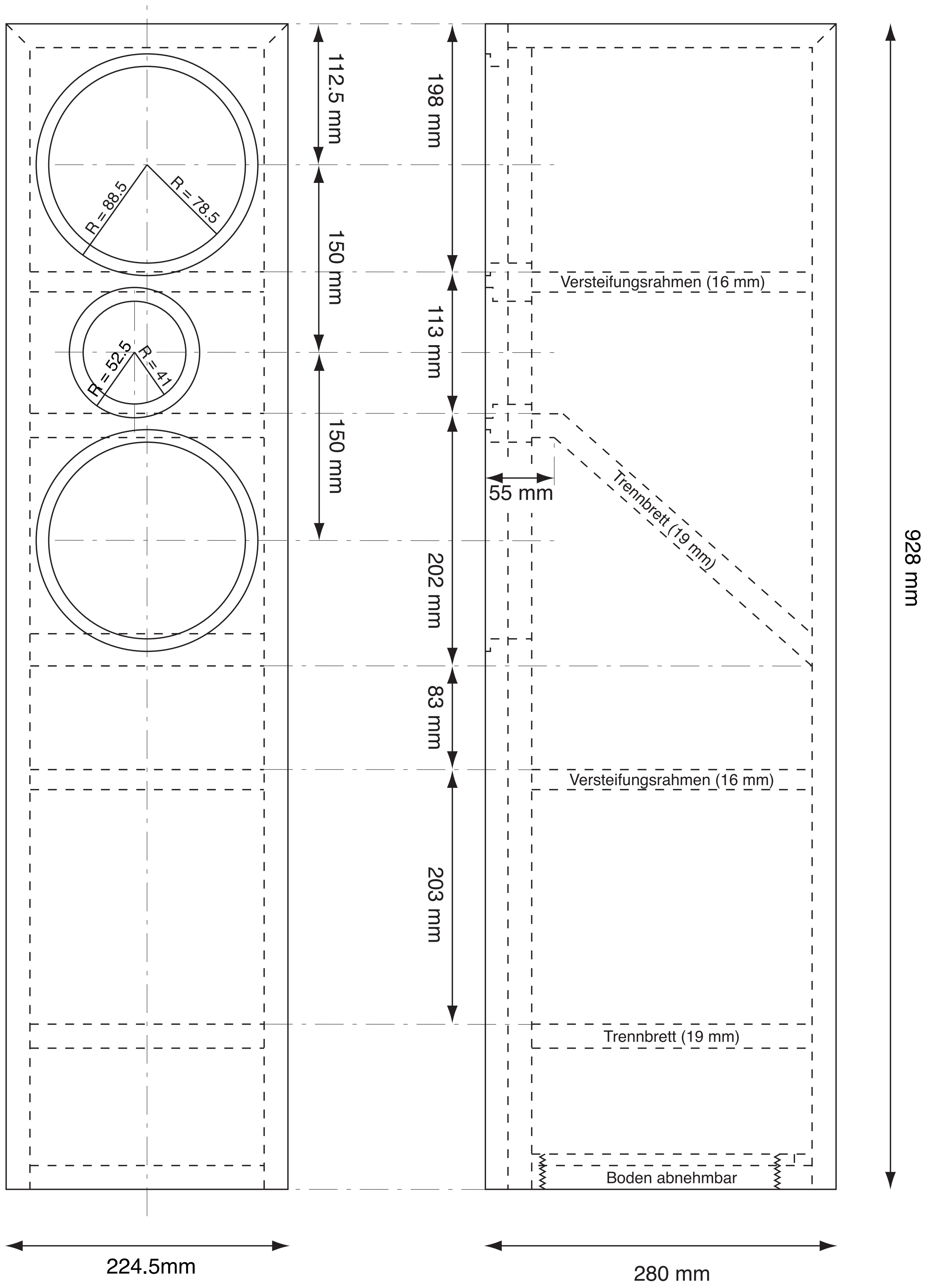

Figure 1: Enclosure drawing of my S24. The midwoofer offset relative to the front baffle is not shown.

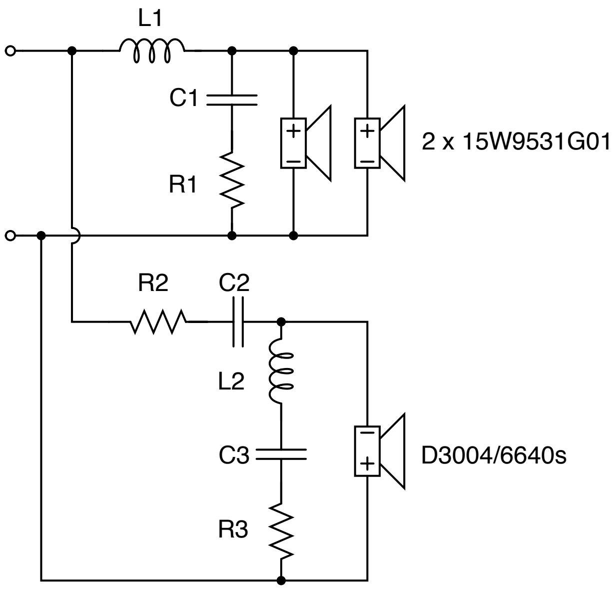

Figure 2: Passive crossover network designed by AOS

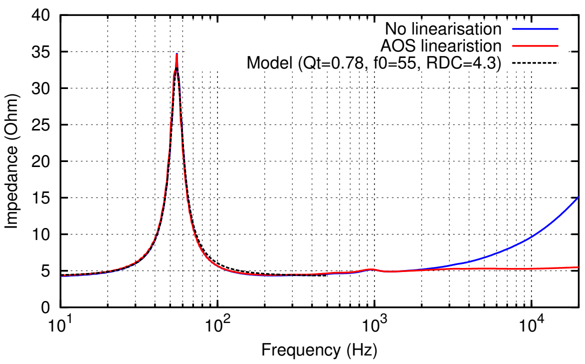

Figure 3: Impedance curves of the two 15W9531G01 midwoofers (parallel) in the box (raw and with linearisation network as designed by AOS). The model curve reflects the impedance of the low-frequency equivalent network of the midwoofers in the closed boxes.

linearisation network results in an impedance range of about 3.6 Ω to 5.5 Ω in the entire frequency range of 150 Hz and above. The linearisation removes most of the impedance peak at about 500 Hz, but does not flatten the peak completely.

Fig. 5 shows the anechoic frequency responses of the tweeter and the midwoofers without filters. The tweeter response shows a 5 dB dip at 3 kHz to 5 kHz, which is due to echoes originating from reflections at the aluminium rings of the protruding midwoofers (the wiggles in the step response shown in Fig. 6). The echoes do not occur in the midwoofer response, because the aluminium rings do not interfere with the sound waves emitted by the midwoofers. The frequency response of the midwoofers is therefore smooth, but rises by about 5 dB from 1 kHz to 2.5 kHz due to the transition from 2π sound emission at low frequencies to 1π at high frequencies (baffle step).

Fig. 7 shows the anechoic frequency response of the drivers with the crossover network filters. The filters result in

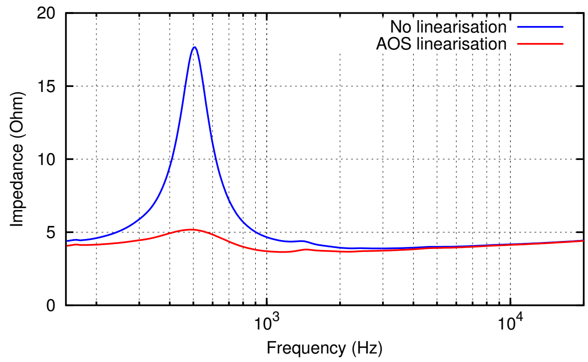

Figure 4: Impedance curves of the D3004/664000 tweeter (raw and with linearisation network as designed by AOS)

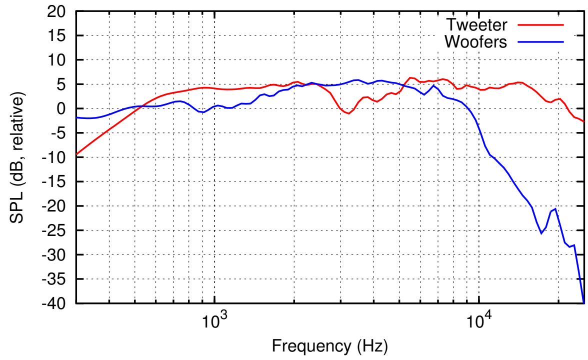

Figure 5: Anechoic frequency responses of tweeter and midwoofers mounted in box, without filters

the desired smooth roll off of the midwoofer and tweeter responses. Due to the flat filter characteristics, the acoustic crossover frequency is not very well defined, but lies in the range of 2 kHz to 3 kHz. The responses of the midwoofers and the tweeter add up nicely. This shows that the sound waves emitted by midwoofers and the tweeter are in phase at the crossover frequency range. The sum response is rather flat, except that it tends to be a wee bit high a 4 kHz to 10 kHz. The dip in the tweeter response at 3 kHz to 5 kHz still shows in the sum response, but it is attenuated because the midwoofers still contribute significantly to the sum response in this frequency range.

Fig. 8 shows the in-room frequency response of S24 as calculated using a 200 ms time window from the start of the impulse response. This takes into account the echoes from the room walls, furniture, and other objects in the room. The $1/12$ octave smoothed response is very flat and looks similar to the anechoic response, except that the treble is a bit lower and, most importantly, the maximum of the "tweeter dip" is reduced further.

Fig. 9 shows the off-axis dispersion of the S24. Horizontal dispersion is very homogeneous, with less than 3 dB attenuation at 30° up to 10 kHz. The vertical dispersion is also rather smooth. In particular, the 3 kHz to 5 kHz dip is reduced to a narrower frequency band if the microphone is offset vertically by 10°, because the echoes from the upper and the lower aluminium rings are separated from each

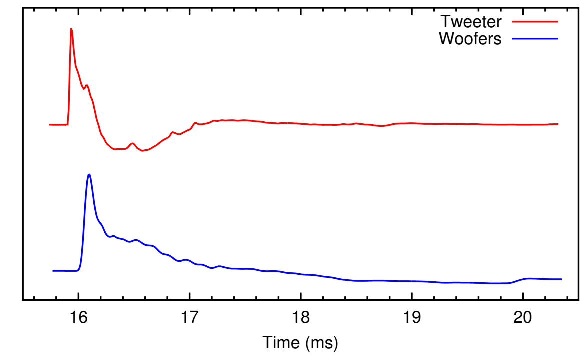

Figure 6: Step responses of tweeter and midwoofers mounted in box, without filters

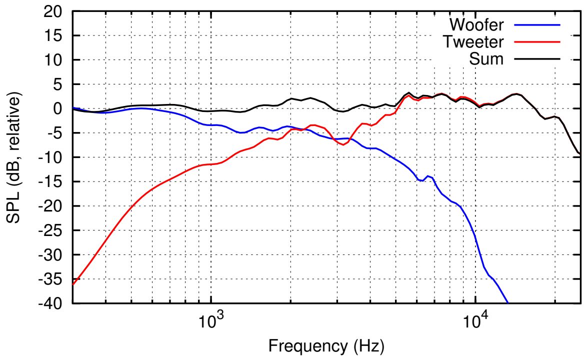

Figure 7: Anechoic frequency response with original AOS crossover network (woofers, tweeter, and sum; measured at 1 m distance from the front baffle, on the tweeter axis)

other.

Fig. 10 shows the step response of the S24 at different angles. The general shape of the step response is very similar to the theoretical ideal. There is only one large pulse, very much like a single-driver loudspeaker. The pulses emitted by the midwoofers and the tweeter are perfectly time coherent. Apart from this, the step response shows a few tiny wiggles, which I attribute to echoes originating from the aluminium rings and the edges of the front baffle (see also Fig. 6).

4.2. Modified passive crossover network. The original crossover network designed by AOS does the job very well, and I see no reason for major modifications of the AOS filter. The only points that might offer some room for improvement are the impedance linearisation of the tweeter and the tendency for a slightly high SPL response of the tweeter.

The tweeter impedance linearisation can be improved by using a lower R_3 value and a slightly larger C_3 value in the impedance compensation network (Tab. 1). The result is shown in Fig. 11. However, the effect on the high-pass transfer function of the tweeter filter is so small that the difference in the SPL response is beyond the measurement precision and therefore seems to be irrelevant.

The slightly high level of the tweeter is remedied by using

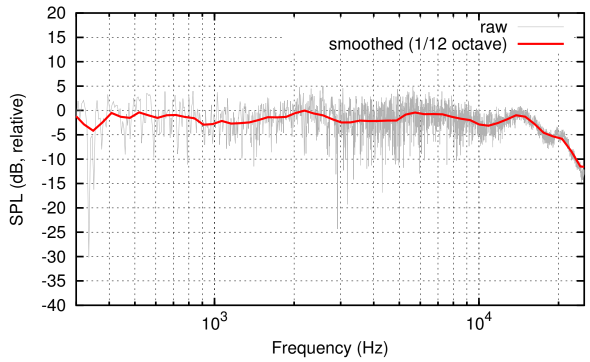

Figure 8: In-room frequency response (calculated using the first 200 ms of the impulse response, measured at 1 m distance from the front baffle on the tweeter axis)

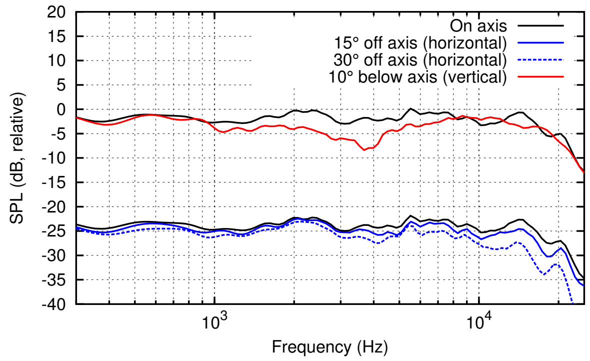

Figure 9: Anechoic frequency response at different angles relative to the tweeter axis (measured at 1 m distance from the front baffle)

a higher R_2 value in combination with a lower C_2 value (Tab. 1). Fig. 12 shows the resulting tweeter responses and the sum response with the midwoofers. The sum response varies by less than ±1.5 dB (300 Hz to 18 kHz).

4.3. Active crossover filter. While the passive filter works very well, one might consider the rather slow 6 dB/octave roll off to be insufficient. However, steep filters are hard to get right with passive networks, because this requires a large number of large parts that are either far from the theoretical ideal or very expensive (or both). Therefore, I decided to test an active filter with steep filter slopes.

I used a THEL SAW30 active filter, which provides 24 dB/octave filters with the additional option for compensation of the baffle step by boosting the audio signal at low frequencies. Fig. 13 shows the S24 frequency response with the SAW30

Table 1: Comparison of part values in original and modified filter network

	original (AOS)	modified
R_2	3.3 Ω	4.7 Ω
C_2	5.6 µF	4.7 µF
R_3	3.9 Ω	2.2 Ω
C_3	78 µF (68 µF + 10 µF)	86 µF (68 µF + 18 µF)

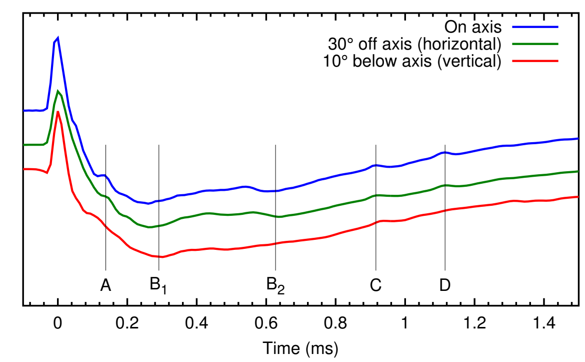

Figure 10: Step response at different angles relative to the tweeter axis (measured at 1 m distance from the front baffle). A: echo of the tweeter sound wave reflected at the aluminium rings. B1–B2: superposition of echoes reflected at the baffle edges and the aluminium rings. I don't know the origin of echoes C and D.

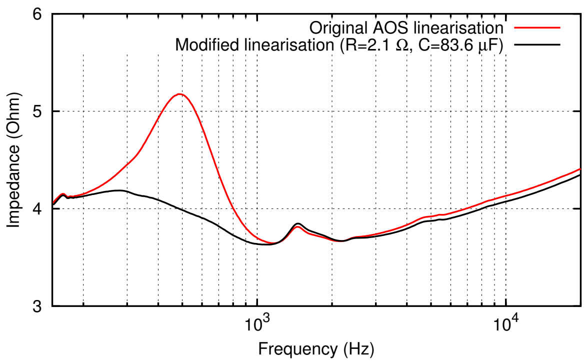

Figure 11: Impedance curves of the D3004/664000 tweeter with original AOS linearisation network and modified network

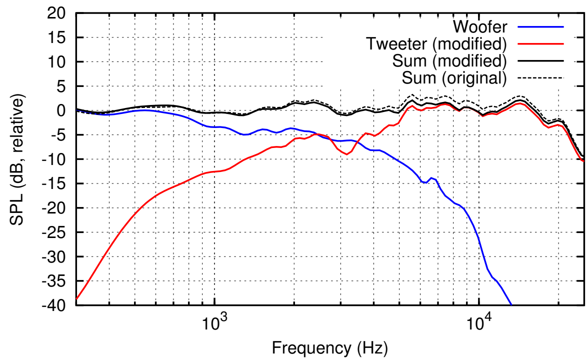

Figure 12: Anechoic frequency response with modified tweeter filter network (red) in comparison to the original AOS filter. The midwoofer filter is identical to the original AOS filter.

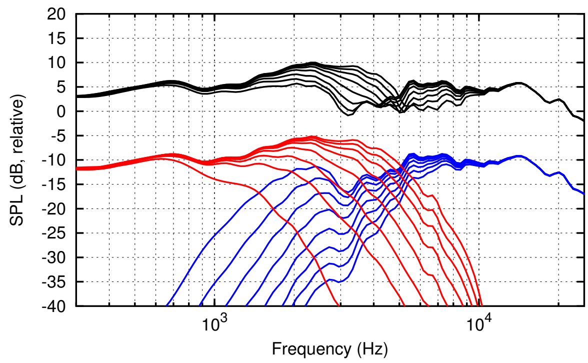

Figure 13: Anechoic frequency response of the S24 midwoofers (red), tweeter (blue) and sum (black) with the THEL SAW30 active crossover filter at different crossover-frequency settings (f_c = 1419 Hz, 1975 Hz, 2482 Hz, 3039 Hz, 3611 Hz, 4167 Hz, 4675 Hz, and 5231 Hz)

at different crossover-frequency settings. For crossover frequencies of 3 kHz and higher, the rise of the midwoofer response due to the baffle step results in an increase by up to 5 dB from 1 kHz to 2.5 kHz.

Based on this overview of the results obtained from the different SAW30 filter settings I optimised the S24 frequency response. The result is shown in Fig. 14. Due to the steep filter slopes, the midwoofer contribution to the SPL in the frequency range of 3 kHz to 5 kHz is negligible. The dip in the SPL response in this frequency range is therefore much larger than with the 6 dB/octave filters used in the passive filter.

The step response of the S24 with the SAW30 active filter shows a separation of the peaks from the tweeter and the midwoofers (Fig. 15). The sound waves emitted by the tweeter and the midwoofers are therefore not time coherent.

Overall, the measured performance of the S24 seems to be better with the first-order passive filters with the fourth-order SAW30 active filters.

5. ADDING A SUBWOOFER

Although the S24 midwoofers are capable of producing surprisingly clear and strong bass, they are rather small. Also, they are mounted in a closed box, which contributes to the clarity and precision of the bass, but does not support a deep and strong bass. The midwoofer resonance frequency of the S24 is 55 Hz (Fig. 3), which is also corresponds to the –3 dB cut-off frequency of the closed box. Also, due to the small size of the midwoofers, moving enough air at low frequencies requires large membrane excursions. Moving the voice coils far from their zero position results in increased distortion throughout the entire frequency band.

I therefore decided to relieve the S24 from playback of deep bass notes, and to use a dedicated a subwoofer for playback of the lowermost octave (say 30 Hz to 60 Hz) instead. The subwoofer[2] should be used for playback of very low frequencies only (100 Hz or less) to prevent acoustic localisation of the subwoofer.

To filter a loudspaker at about 60 Hz an active filter inserted before the power amplifier is required. Fig. 16 shows the

[2] I used an active subwoofer with 12 inch Peerless drivers, see `http://audioroot.net/peerless-subwoofer`.

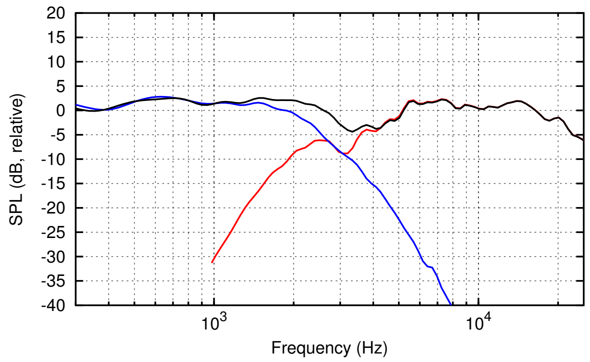

Figure 14: Anechoic frequency response of the S24 midwoofers (red), tweeter (blue) and sum (black) with the THEL SAW30 active crossover filter with switches 1, 2 and 4 set to 2482 Hz, and switch 3 set to 1975 Hz. The baffle step compensation was set to 12 h with C = 33 nF.

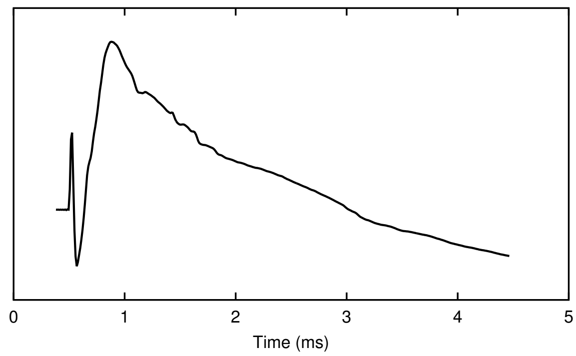

Figure 15: Step response of the S24 with the THEL SAW30 active crossover filter with switches set as in Fig. 14.

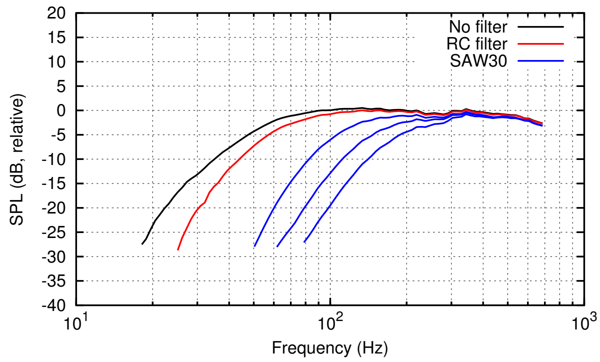

Figure 16: S24 bass frequency response measured in the nearfield to gate out room echoes (without filter; RC filter at input of power amplifier, see text; THEL SAW30 set to cut-off frequencies 95 Hz, 132 Hz, 165 Hz)

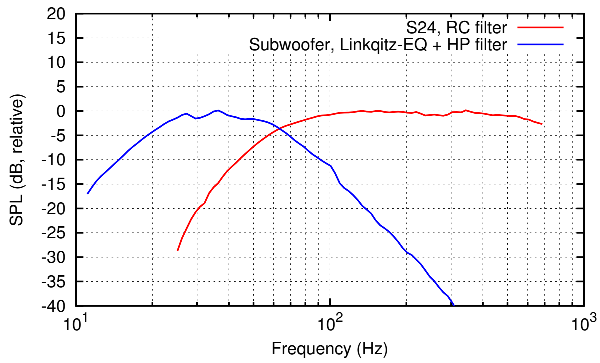

Figure 17: Bass frequency responses of the S24 and the subwoofer, measured in the nearfield to gate out room echoes (S24 with RC high-pass filter, subwoofer with 18 dB/octave low-pass filter and Linkwitz pole-zero equalisation)

bass frequency response of the S24 without a high-pass filter compared with different “active” filter options.

The first option is a 0.32 µF capacitor inserted in the signal path at the input of the power amplifier. This capacitor forms a RC high-pass filter with the input resistance of the power amp (I use a HifiAkademie PowerAmp version 3, with 10 kΩ effective input resistance). Combined with the closed-box second-order roll off of the S24 midwoofers (12 dB/octave), this first-order RC filter results in a third-order roll-off with a –3 dB point of about 65 Hz. The beauty of this approach is that almost every power amplifier comes with a input capacitor anyway–all that’s required is to replace the input capacitor with a smaller value capacitor. The RC-filter approach therefore does not add anything to the signal path. However, the RC filter is only useful if it’s tuned to the cut-off frequency of the unfiltered driver/box system. At higher frequencies, the RC filter results in a slow 6 dB/octave roll off, which is not very useful in combination with a subwoofer.

The second option is an active filter such as the SAW30 as described in Sec. 4.3. The steep SAW30 filters allow using the filter at higher frequencies than the RC filter. However, using the SAW30 also means that a rather complex circuit is inserted into the signal path. Another challenge with the SAW30 option is that a cut-off frequency of about 100 Hz or less is required. Operating the SAW30 cut-off frequencies lower than those in Fig. 16 would lead to a overlap of the closed-box 12 dB/octave roll off with the 24 dB/octave slope of the SAW30. This would sum up to an overly steep low-frequency slope which would be difficult to match with the subwoofer.

Overall, the RC filter seems to be a simpler solution that does not add any additional complexity that might affect the signal integrity any way. I therefore prefer the RC filter.

Fig. 17 shows the low frequency responses of the S24 and the the subwoofer. The crossover frequency is 63 Hz, and the subwoofer response extends down to a –3 dB frequency of about 21 Hz. The subwoofer high-pass slope is 18 dB/octave, which matches the low-pass slope of the S24.

REFERENCES

[1] M S Brennwald. MATAA: A free computer-based audio analysis system. *audioXpress*, (7):36–41, July 2007.

[2] Joseph D'Appolito. *Testing Loudspeakers*. Audio Amateur Press, Peterborough, New Hampshire, USA, 1998.