The Open Source Monkey Coffin Loudspeaker

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IMPORTANT NOTES AND DISCLAIMERS

This document describes the design of the Open Source Monkey Coffin (OSMC) loudspeaker, which was developed in an “open-source project”.[1] The aim of this project is to provide the OSMC design to DIYers for their own private purposes, for example to build a copy of the OSMC. Do not use the information developed in this project on a larger scale without written permission (for example by selling speakers based on the OSMC design or substantial parts of it).

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1. OVERVIEW

The Open Source Monkey Coffin (OSMC) loudspeaker was developed by members of the diyAudio internet forum.[1] The motivation for developing this loudspeaker emerged from two diyAudio threads discussing the idea of “open source” loudspeaker designs.[2,3] Once the types of loudspeakers that would appeal to many novice DIYers were identified, the design targets for the OSMC were defined as follows:

- The OSMC must be straight forward to make for DIY novices.
- The box format should follow the “large monitor” format, sometimes also referred to as “monkey coffin” (hence the name). The internal volume should not be larger than 60–80 L. The enclosure must be a simple rectangular box which is easy enough to make on a kitchen table.
- The OSMC should be “amplifier friendly”. It should work well with small amplifiers like the popular Amp-Camp-Amp, tube amps, etc.
- The OSMC should be a three way loudspeaker.
- Keeping part costs low is not of paramount priority. If the right parts cost a lot of money and there are no cheaper equivalents, it’s okay to use those parts in the design.

For “amplifier friendliness”, the loudpseaker efficiency was targeted to 92 dB−SPL at 1 m and 2.83 V input voltage, with a bass extension to 45 Hz (–3 dB). The impedance curve must not exhibit any sharp peaks or dips, and the OSMC should qualify as an “8 Ω speaker”. It must be noted that, given the constraints of the box size, these targets could only be achieved if mechnical losses within the loudspeaker system were virtually zero, which is nearly impossible in real-world loudspeakers. While it is therefore not realistic to fully implement these design targets, these targets still provide useful guidelines for the design process.

The following is a brief summary of the design process, which is fully documented in the diyAudio thread.[1]The OSMC design was aided by the use of loudspeaker CAD tools (LEAP, Vituix CAD, Tolvan Edge). Measurement data were acquired using an RTX6001 USB audio analyser, MATAA software, and Earthworks M23 and iSEMcon EMX-7150 microphones. Data from measurements and simulations are available in the OSMC data repository.[4]

2.1. Drivers

High-quality drivers and parts should be chosen based on the technical specations required for the OSMC design. The look of the drivers has to be “right” for a HiFi system in a home environment (people may not want to build a speaker that looks unusual), but is second priority after the techincal specifications.

The woofer will determine the compromise between box size, bass-extension, and efficiency. The size of the woofer critically determines the efficiency of the loudspeaker, and a 12" woofer will just fit the targeted box size. After screening numerous woofers based on their manufacturer specification, two drivers were identified that should allow high efficiency at the targeted –3 dB point of 45 Hz (FaitalPro 12PR320 and the D.A.S. Audio 12P).[5] Measurements of the Thielle-Small parameters showed that the mechanical losses of the D.A.S. Audio driver are considerably higher than speciefied in the datasheet, whereas the parameter values observed with the FaitalPro driver were consistent with the datasheet. The FaitalPro driver also showed lower harmonic distortion than the D.A.S. Audio driver.[6] The FaitalPro 12PR320 was therefore chosen as the woofer in the OSMC.

The midrange driver needs to keep up with the requirements of the sound pressure level (SPL) and impedance. The Volt VM752 dome driver will work very well from 400 Hz up to about 3 kHz. While there may be other midrange drivers that could be used, the VM752 was chosen due to the general interest for this driver and because some of the OSMC designers had good experience using this driver.

The tweeter also needs to keep up with the SPL and impedance requirements. Classical dome or ring radiator tweeters were preferred by the OSMC designers. Also, the use of a waveguide seems favourable in order to match the dispersion of the tweeter to the midrange, to reduce the effects of baffle diffraction, to increase the on-axis efficiency, and to reduce non-linear distortion of the tweeter. Tweeters with high directivity tend to minimize acoustic interference with the waveguide at wavelengths similar to the throat diameter, which helps to avoid large SPL wiggles at high frequencies.[7] Therefore, the Scan Speak R2904/7000 ring radiator was chosen. The R2904/7000 also features high electrical impedance, high efficiency, and very low harmonic distortion. Most of the design work was done with a Visaton WG148 waveguide, which was modified to fit the R2904/7000.[8] However, the final design uses a custom-made waveguide, which was designed specifically for use in the OSMC by diyAudio user augerpro.[9] The augerpro waveguide is acoustically almost identical to the WG148,[10] but is very easy to fit on the R2904/7000. It is available for purchase via group buy at diyAudio.[11]

Fig. 1 and Fig. 2 show the impedance and the SPL response of the drivers mounted in the OSMC box. These data were used as the basis for electro-acoustical modelling of the crossover filters.

The SPL response curves were obtained from gated impulse-response measurements, which yielded the anechoic SPL response above 300 Hz. Measurements were taken at horizontal angles from –90° to 90° at 15° steps. The low-frequency parts of each SPL curve were calculated from the Thielle-Small parameters of the drivers (using LEAP) and a diffraction model of the Monkey Coffin baffle (using Vituix CAD).[12] The anechoic part and the low-frequency part of each SPL curve were merged using a "soft splice" in the frequency range where both parts of the curve overlapped consistently.[13] Finally, the phase response (not shown in Fig. 2) was determined by calculating the minimum phase from each of the merged SPL curves. The drivers show smooth SPL response curves throughout their intended operating range. The on-axis on-axis response of the Volt VM752 midrange shows a dip at 2.3 kHz. This dip disappears in the off-axis curves, which indicates that this is an uncritical diffraction artifact related to the driver/waveguide geometry rather than a problematic resonant effect.

2.2. Baffle and Enclosure

Fig. 3 shows the OSMC enclousure. The dimensions of the baffle are largely deteremined by the space required for the drivers. The tweeter and midrange are horizontally offset relative to the center in order to spread effects of diffraction at baffle edges over wide frequency band as much as possible.

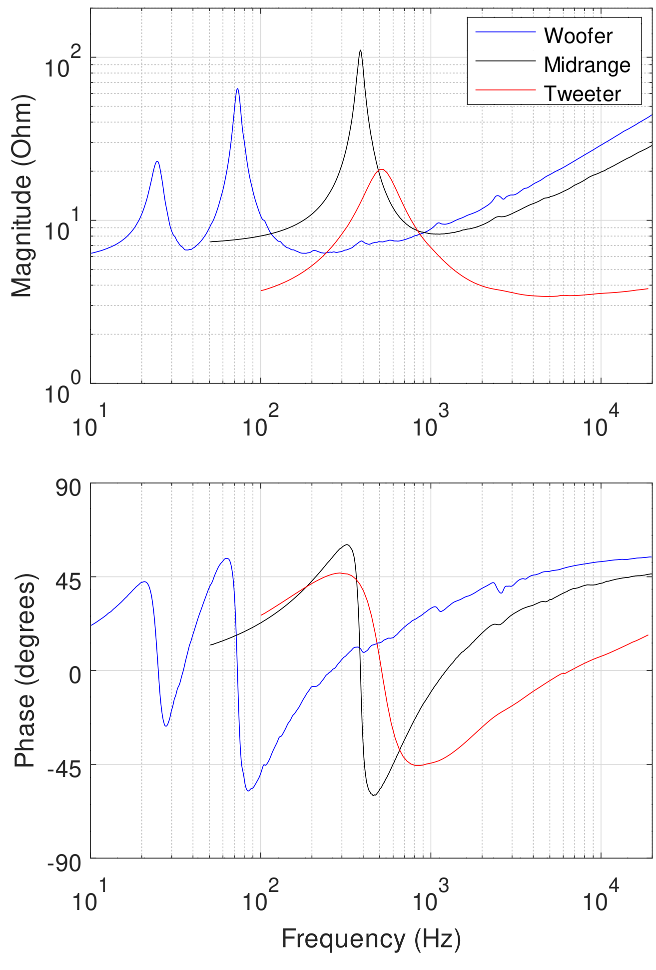

Figure 1: Impedance curves of the drivers mounted in the OSMC box (magnitude and phase).

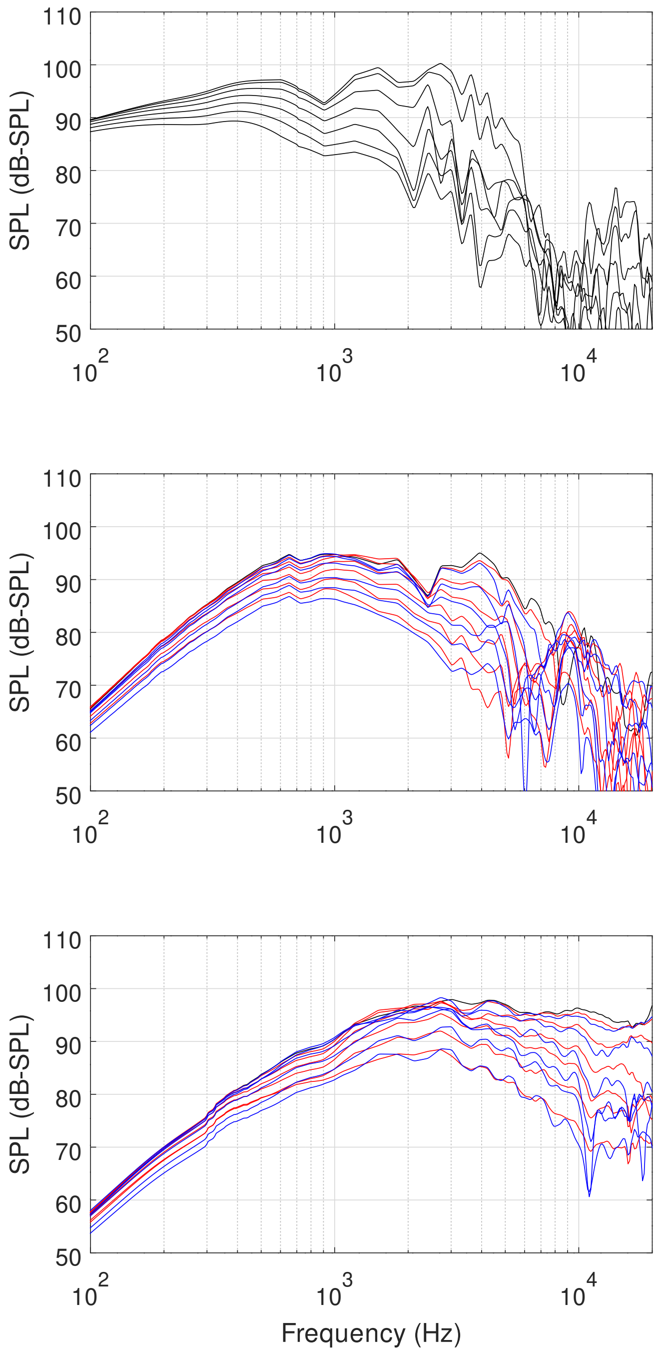

Figure 2: SPL response curves of the woofer (Faital 12PR320, top), midrange driver (Volt VM752, center) and tweeter (Scan Speak R2904/7000 with WG148 waveguide) mounted in the Monkey Coffin prototype box, measured at 2.83 Vrms and 1 m distance from the drivers, on axis and at $\pm 15^\circ$, $\pm 30^\circ$, $\pm 45^\circ$, $\pm 60^\circ$, $\pm 75^\circ$ and $\pm 90^\circ$ horizontal angles (the red curves were measured on the side where the tweeter and midrange drivers are closer to the baffle edge, the blue curves are from the other side; the woofer data is symmetric). Above 300 Hz, the curves show the anechoic response as obtained from gated impulse-response measurements. The anechoic curves were extrapolated to lower frequencies by splicing them with modelled low-frequency curves (see text).

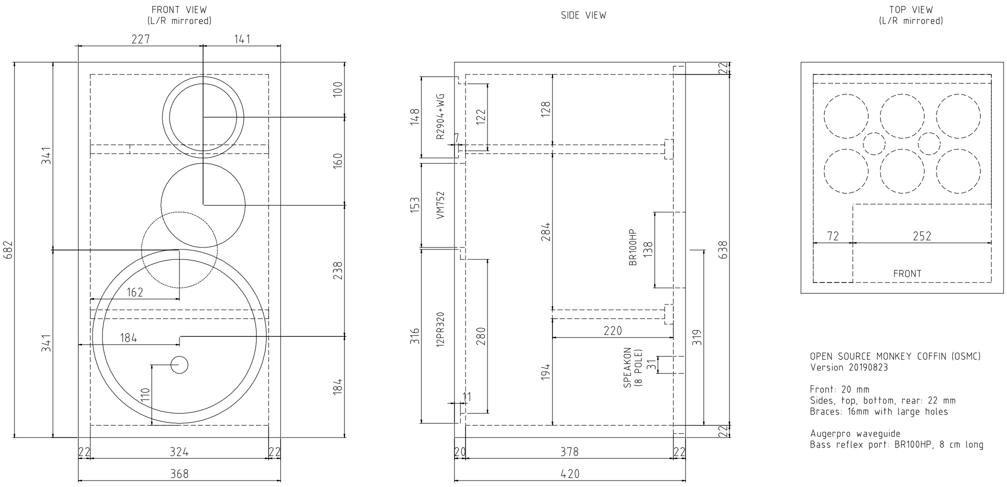

Figure 3: Drawing of the OSMC enclosure. Notes: (1) the horizontal driver offsets are mirrored in the left and right speakers; (2) the rear must be removable for installation of the Volt VM752 driver; (3) the front needs to be 20 mm thick to fit the Volt VM752 flange; (4) the speaker terminal hole shown here fits a Neutrik NL8MPR-BAG 8-pole Speakon terminal (adjust as suitable).

The volume of the box and the dimensions of the bass-reflex port were determined using simulations and measurements of the bass tuning. The goal was to obtain flat SPL response down to the cut-off frequency. In order to keep group delay low, the bass SPL curve was designed to roll off smoothly Fig. 4 shows the 2π free-field bass SPL response and the corresponding group delay. The SPL curve was determined using the mic-in-box technique for data up to 110 Hz, which were spliced to a near-field measurement from 90 Hz upwards. Note that this 2π SPL curve assumes an infinite baffle and therefore does not show the effects of baffle diffraction as it occurs at the transition from the 4π radiation at low freqencies to 2π at higher frequencies (see also Sec. 2.3).

2.3. Crossover filters

The cross over filters are implemented as passive circuits using steep filters in order to achieve small overlaps between the drivers in the crossover frequency bands, which reduces acoustic interferences between the drivers.

Full compensation for the baffle diffraction loss was designed into the crossover filters. The modelled curves of the diffraction loss were subtracted from the 2π SPL response curves of the raw drivers (see Sec. 2.1). These SPL curves were used to design the filters to achieve a balanced 4π SPL response.

Two different filter types were considered during the prototyping process.[14] The first prototype uses elliptic filters, which are not very widely used in conventional

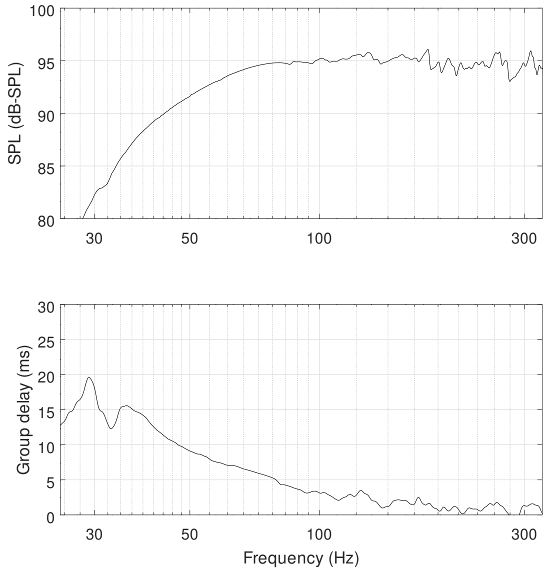

Figure 4: Bass SPL and group delay (2π free-field, 2.83 Vrms drive voltage, at 1 m; see text).

loudspeaker designs. While the transfer functions of elliptic filters may exhibit some ripple near their cut-off range, they allow very steep slopes. The second prototype was designed with simpler and more conventional circuit topology using series inductors and parallel capacitors for the low-pass sections, and vice-versa for the the high-pass sections. Both prototypes were optimized for smooth and flat overall system SPL response, smooth dispersion and power response, and symmetric acoustic filter slopes near the cross-over points. The summed SPL curves in the filter simulations were virtually identical.

Both filter prototypes were implemented for testing in the OSMC prototype using a miniDSP digital signal processor. Acoustic measurements and listening tests with these DSP filters showed that both filters result in similar results, although with the elliptic filters the sound was perceived to be slightly more refined.[15] The elliptic filters were therefore implemented as passive circuits and further optimized using acoustic measurements and listening tests. The schematic of the final cross-over filters is shown in Fig. 5, with the part specifications in Tab. 1. Note that the manufacturers and type numbers of the parts suggested in the table correspond to the parts used in the prototype. These are high quality parts and work well, but they may be substituted with other parts with the same specifications.

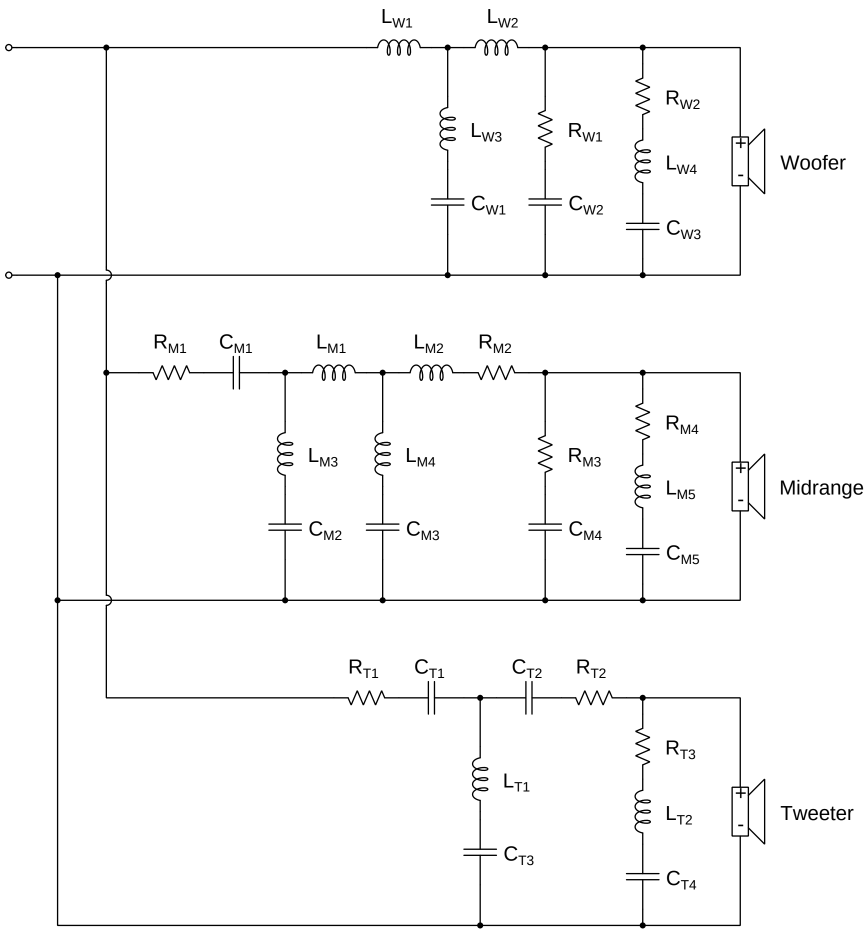

Figure 5: OSMC cross-over filters (elliptic).

Table 1: List of parts in Fig. 5 (version 2019-08-23).

Part	Value	Description
L_{W1}	6.8 mH / 0.19 Ω	Laminated iron core (e.g. Mundorf BS180, Feron, I core, baked varnish)
L_{W2}	1.8 mH / 0.09 Ω	Laminated iron core (e.g, Mundorf BS180, Feron, I core, baked varnish)
L_{W3}	0.1 mH / 0.23 Ω	Air core (e.g. Mundorf BL71, baked varnish)
L_{W4}	15 mH / 1.12 Ω	Iron core (e.g, Mundorf BH71, Ferrite, baked varnish)
C_{W1}	118 µF	Parallel combination of 100 µF bipolar electrolytic (e.g. Mundorf ECAP50) and 18 µF MKP (e.g. Mundorf MCAP250)
C_{W2}	33 µF	Bipolar electrolytic (e.g. Mundorf ECAP70)
C_{W3}	267 µF	Parallel combination of 220 µF and 47 µF bipolar electrolytics (e.g. Mundorf ECAP63 / ECAP50)
R_{W1}	6.8 Ω / 10 W	MOX type (e.g. Mundorf MR10)
R_{W2}	5.6 Ω / 10 W	MOX type (e.g. Mundorf MR10)
L_{M1}	1.2 mH / 0.39 Ω	Air core (e.g. Mundorf BL125, baked varnish)
L_{M2}	0.33 mH / 0.15 Ω	Air core (e.g. Mundorf BL100, baked varnish)
L_{M3}	6.8 mH / 0.46 Ω	Iron core (e.g. Mundorf BH100, Ferrite, baked varnish)
L_{M4}	0.12 mH / 0.15 Ω	Air core (e.g. Mundorf BL100, baked varnish)
L_{M5}	2.7 mH / 1.01 Ω	Iron core (e.g. Mundorf BP71, Ferrite, baked)
C_{M1}	33 µF	MKP (e.g. Mundorf MCAP250)
C_{M2}	267 µF	Parallel combination of 220 µF bipolar electrolytic (e.g., Mundorf ECAP63) and 47 µF MKP (e.g. Mundorf MCAP250)
C_{M3}	6.8 µF	MKP (e.g. Mundorf MCAP250)
C_{M4}	4.7 µF	MKP (e.g. Mundorf MCAP250)
C_{M5}	68 µF	Bipolar electrolytic (e.g. Mundorf ECAP50)
R_{M1}	2.7 Ω / 10 W	MOX or wire wound (non-inducitve) (e.g. Mundorf MRES20)
R_{M2}	5.6 Ω / 10 W	MOX or wire wound (non-inducitve) (e.g. Mundorf MRES20)
R_{M3}	8.2 Ω / 10 W	MOX or wire wound (e.g. Mundorf MR10)
R_{M4}	8.2 Ω / 10 W	MOX or wire wound (e.g. Mundorf MR10)
L_{T1}	0.18 mH / 0.38 Ω	Air core (e.g. Mundorf BL71, baked varnish)
L_{T2}	0.47 mH / 0.64 Ω	Air core (e.g. Mundorf BL71, baked varnish)
C_{T1}	4.7 µF	MKP (e.g. MCAP250)
C_{T2}	15 µF	MKP (e.g. MCAP250)
C_{T3}	100 µF	Parallel combination of 82 µF bipolar electrolytic and 18 µF MKP (e.g. Mundorf ECAP50-82 and MCAP250-18)
C_{T4}	100 µF	Bipolar electrolytic (e.g. Mundorf ECAP50)
R_{T1}	3.9 Ω / 10 W	MOX or wire wound (non-inducitve) (e.g. Mundorf MRES20)
R_{T2}	1.0 Ω / 10 W	MOX or wire wound (non-inducitve) (e.g. Mundorf MRES20)
R_{T3}	4.7 Ω / 10 W	MOX type (e.g. Mundorf MR10)

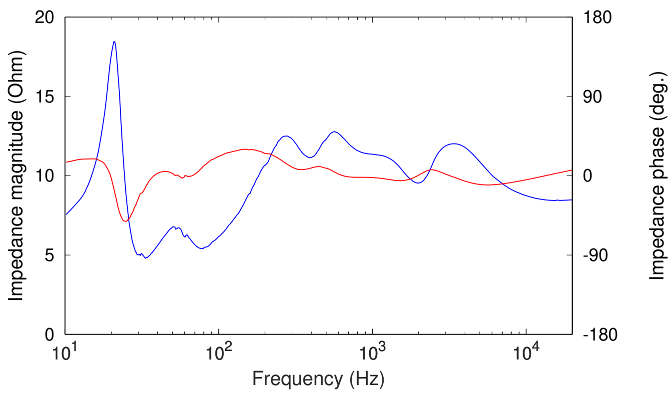

Figure 6: Measured electrical impedance (magnitude in blue, phase in red).

3. CONSTRUCTION

3.1. Baffle and Enclosure

Post showing the enclosure with stuffing and bracing.[16]

*** BRACING

*** DAMPING

*** Fitting the waveguides (augerpro)

3.2. Cross Over Filters

*** how to (not) construct the filters

*** possible modifications (better parts, other part values: use Vituix CAD to see effects)

3.3. System tests and performance

3.4. Electronic

Fig. 6 shows the OSMC impedance vs. frequency. The impedance reaches its minimum value of 4.8 Ohm at 33 Hz, and ranges from 5.5 Ohm to 12.8 Ohm above 45 Hz. There are no sharp variations in the impedance curve, which is also expressed in the rather flat curve of the impedance phase. The OSMC is therefore an easy load for the amplifier, even if the targeted “8 Ohm” rating[17] is valid only above 100 Hz in a strict sense.

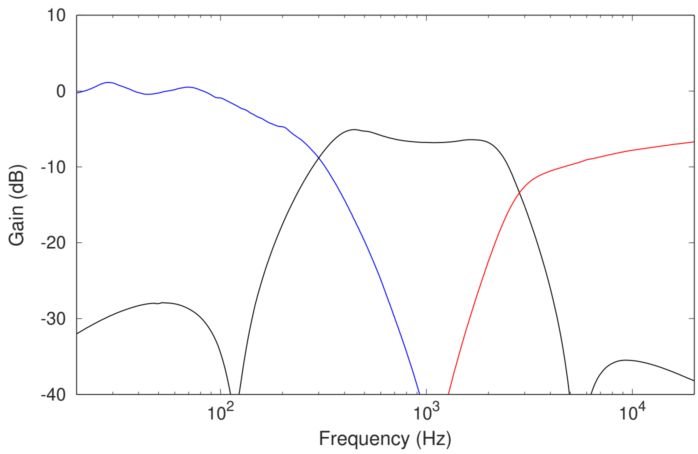

Figure 7: Measured transfer curves of the crossover filters for the woofer (blue), midrange (black), and tweeter (red).

Fig. 7 shows the OSMC filter transfer curves (***WORK: THIS IS THE 2019-03-03 FILTER VERSION. NEED TO REPLACE THIS WITH THE 2019-08-23 CURVES, WHERE THE KINK IN TWEETER CURVE IS SMOOTHER). The leakage in the stop bands of the elliptic filters is obvious for the midrange filter. However, the efficiency of the midrange driver in the respective frequency bands is very low Fig. 2, and the attenuation in the stop bands is –25 dB or better. The filter leakage is therefore considered irrelevant.

3.5. Acoustic

*** step response (at 1m / farfield) *** farfield anechoic SPL curves of full system and individual drivers (padded with woofer response measured with filters – either at 4pi or at 2pi + baffle-step model curve). Also show SPL curve with midrange inverted polarity to indicate the x-over frequencies. *** cumulative decay spectrum *** polar plots (horizontal, vertical)

3.6. Listening impressions

The OSMC was designed for accurate music playback in a home environment with “amplifier friendliness” in mind. Listening tests were therefore conducted with a 11 W tube amplifier (triode push pull design) and a 25 W solid state amplifier (FirstWatt F5 class-A). These amplifiers had no problems driving the OSMC to “party levels”, which confirms the “amplifier friendliness” of the OSMC.

The overall sound is balanced and coherent, with tight, articulate and well controlled bass. As an inevitable physical consequence of the “amplifier friendliness”, however, the bass is not as deep as with some other similar sized “HiFi” loudspeakers that need to be driven by powerful amplifiers. The OSMC sounds highly transparent and dynamic, both at low and high playback levels. This lack of compression allows good resolution of low-level details even with complex or loud music. The waveguides result in a large proportion of direct sound at the listener position, resulting in precise rendering of the musical scene with little impact of the reverberant sound of the room.

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