Home Theater Speaker HKL-01 Documentation

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March 2011, Hanover

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1 Requirements

The speaker is specifically intended to be used in a home theater. The objectives for the design of this active loudspeaker were as follows:

1. Dispersion behavior that is as constant as possible
2. High maximum output level (low non-linear distortion)
3. The frequency range 20 - 100 Hz is taken over by an external subwoofer system
4. Use behind acoustically transparent screen
5. Ideally wall-mounted

Demand 1 can be reached with a dual-waveguide. This has the advantage that the directivity is not only constant, but also narrow. The room is thus much less excited than with a half-space radiator. At the same time, the waveguide fulfils point 2. This is due to the fact that the sound pressure in the midrange and treble range is higher due to the horn effect.

From 3 it follows that a midwoofer can be used instead of a woofer. Due to the low bandwidth, it can have a high sensitivity and can be installed in a closed housing with a low volume. Intermodulation is thus kept to a minimum. At the same time, this fulfils requirements 2.

From the points 4 and 5 this is followed by an enclosure that is as flat and universally usable as possible without integrated electronics. The power amplifiers and the active crossover should therefore be placed separately. This has the further advantage of being flexible when changing environments.

2 Development

2.1 Drivers

Since the overall concept is largely determined by a fully designed dual-waveguide, the choice of midrange and tweeter drivers was already clear. The waveguide module has been specially developed for the drivers below. Of particular note is Tang Band's 75mm dome midrange, which features very low non-linear distortion.

As described in the previous chapter, the project was designed as a 4-way system. The requirements for the midwoofer driver were thus clearly defined. Above all, it should have the following characteristics:

1. Low bandwidth (only necessary from 100 Hz)
2. High sensitivity
3. Low non-linear distortion
4. High maximum output level

Such midwoofers are only found for the PA usage. The high sensitivity ensures low power compression and low requirements to the power amplifier.
A high maximum output level is achieved by a large linear stroke and/or a large diaphragm area. Since the dispersion behavior should not deviate too much from that of the midrange driver in the waveguide, only one large driver was considered. However, the shallowest possible depth of the speaker cabinet limited the driver’s size. In the end, a 30 cm midwoofer from Beyma was the best compromise. This was installed in a closed volume of approx. 20 litres.

The following components were installed:

Midwoofer: Beyma 12G40
Midrange: Tang Band 75-1558SE
Tweeter: Seas 27TAFC/G (27TAFPlus)

The crossover frequencies are 600 Hz and 2400 Hz. This results from the demand for the most constant directivity possible. Table 1 shows the resulting bandwidths of the individual ways.

Branch	Frequency Response (Hz)	Octaves
Woofer (subwoofer system)	10 – 100	2.2
Woofer	100 – 600	2.5
Midrange driver	600 – 2400	2
Tweeter	2400 – 20,000	3

Table 1: Bandwidths of each driver

The big advantage of the 4-way concept is that the low-frequency range is controlled by an optimized subwoofer system (e.g., Double Bass Array), which can be positioned and configured independently of the rest of the speaker. Furthermore, the lower bandwidth and reduced stroke of the midwoofer driver reduce intermodulation distortion in the lower midrange.

2.2 Enclosure

The enclosure was initially designed with Pro/ENGINEER. The dimensions should be as small as possible.
The contour of the waveguide was developed with ABEC and imported into Pro/ENGINEER. The waveguide module is designed as a stand-alone unit so that it can still be used if the enclosure is exchanged at a later date.

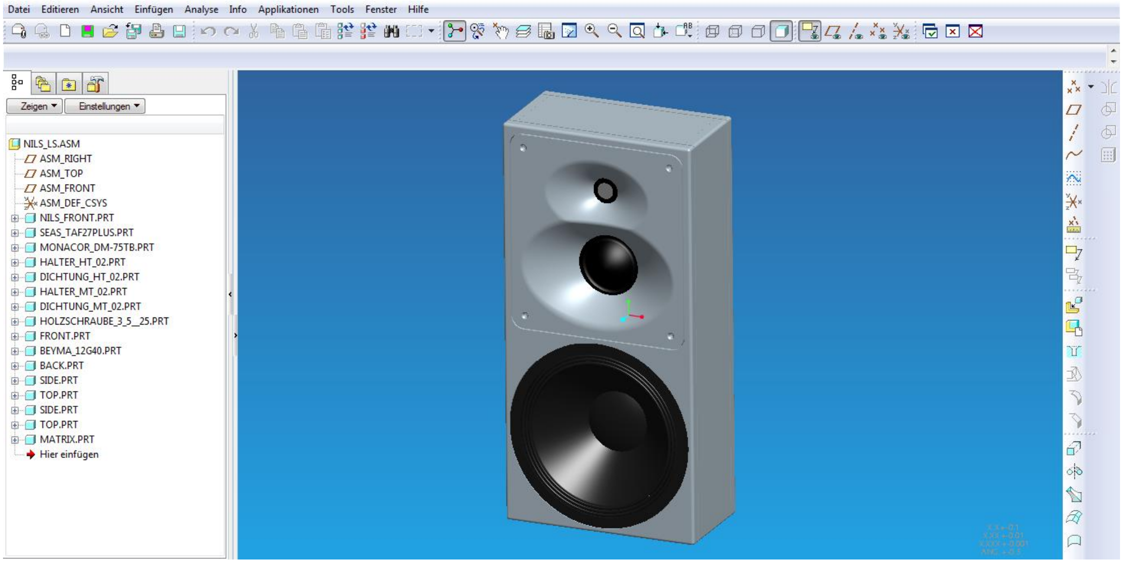

Figure 1: Enclosure design with Pro/ENGINEER

The waveguides were CNC milled from MDF. Subsequently, both parts of the case were painted matt black.

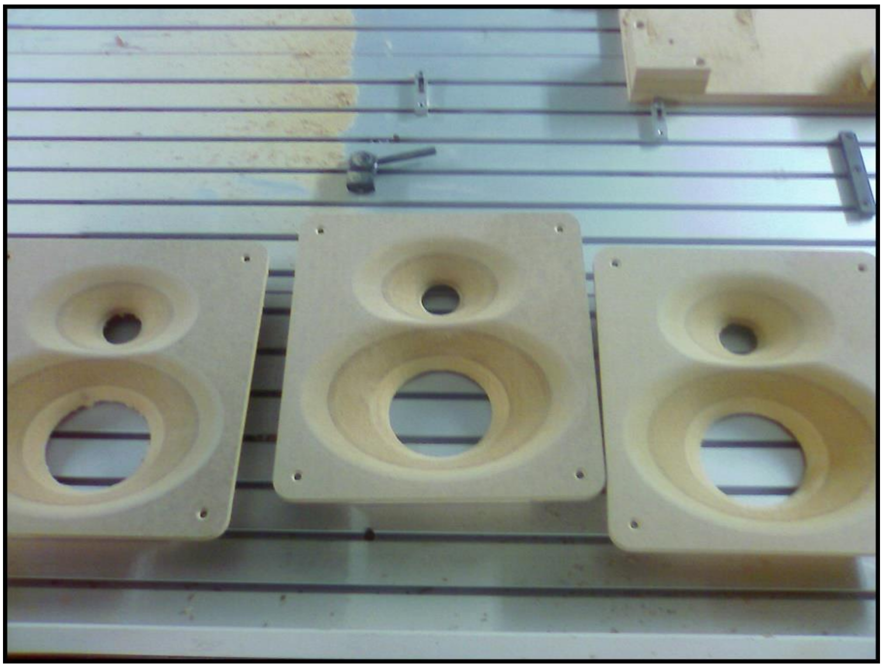

Figure 2: Waveguides after CNC milling

Figure 3: Back of the waveguide modules

Figure 4- Painting of the enclosure parts

Midrange and tweeter drivers were mounted into the recesses in the waveguide module from the rear and then attached to a frame.

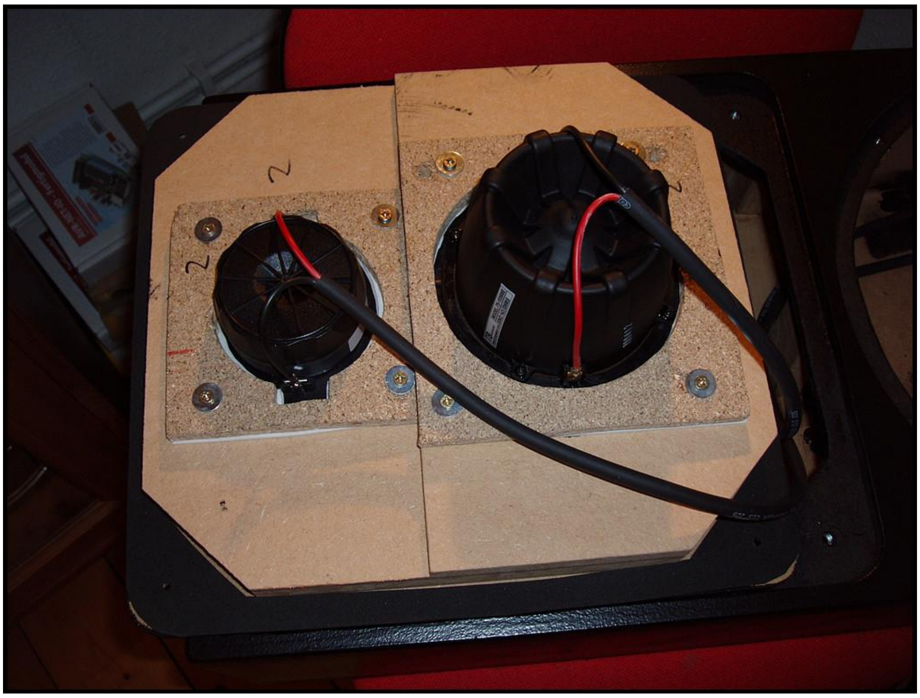

Figure 5: Mount the drivers on the waveguide

The speakers are equipped with an 8-pin speakON jack on the bottom, so that all three drivers can be controlled with a single multicore cable.

Figure 6- speakON connector

Three identical copies were built, which are used as front speakers in the home cinema. They differ only in the position of the speakON connector at the bottom.

Figure 7: Three Fully Assembled Speakers

2.3 Amplifiers

The requirements for the three power amplifiers resulted from the overall concept and the characteristics of the loudspeaker. These were as follows:

1. Sufficient output power for the connected driver
2. Low distortion
3. Small dimensions

The choice of power amplifiers fell on the Hypex UcD180ST. It is a compact Class D power amplifier module with an output power of approximately 160 W RMS at 6 Ω, which is enough even for the bass-midrange driver to achieve mechanical power handling.

Figure 8: Hypex UcD180ST

Even though Class D produces less power dissipation than Class AB, the power amplifiers still require an aluminum plate for heat dissipation. The plate has been designed to be as compact as possible and houses all the necessary input and output sockets in addition to the power amplifiers and the power supply.

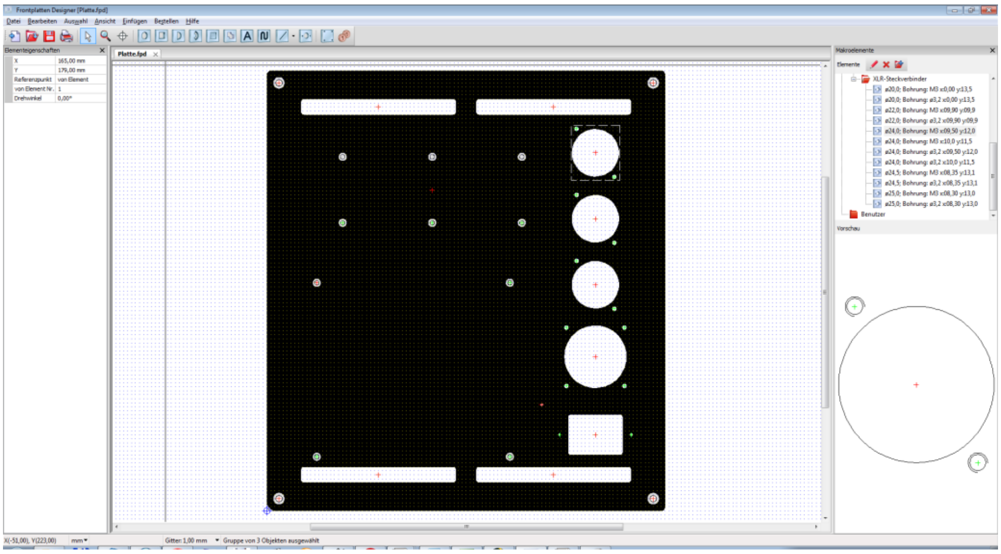

Figure 9: Power amplifier front panel design

The aluminum plate was anodized black by the manufacturer and equipped with threads, so that the assembly of the component groups was very easy. In order to reduce the sensitivity of the power amplifiers and thus reduce the noise of the active crossover, a voltage divider was soldered to the input sockets.

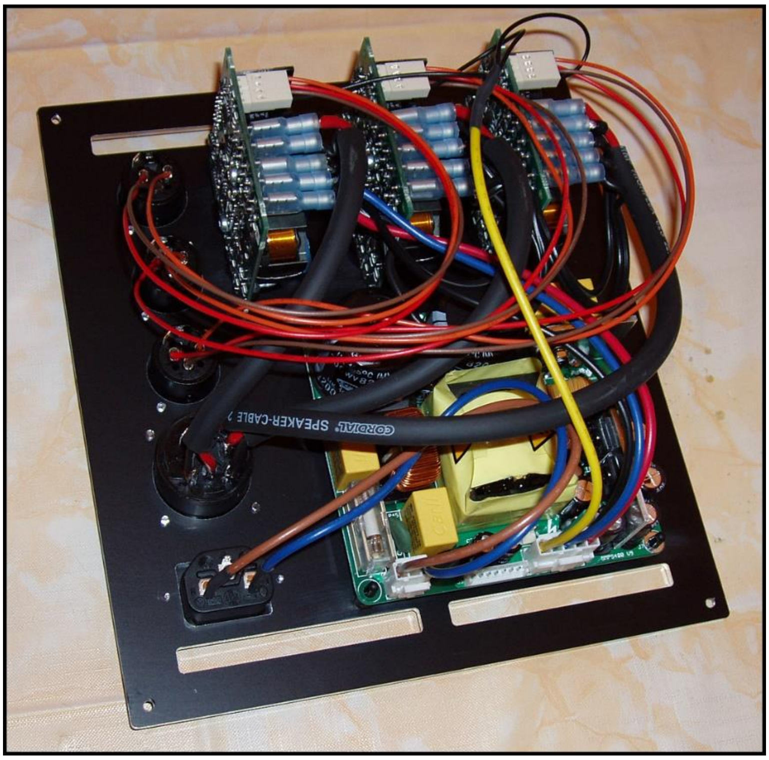

Figure 10: Power amplifiers mounted on aluminum plate

The aluminum plate was then screwed onto a small MDF case. The dimensions of the top are 220 x 200 mm. Due to the shallow depth, the power amplifier housing can be easily integrated invisibly near the wall.

Figure 11: Fully assembled power amplifier housing

2.4 Active crossover

An ALTO Maxidrive 3.4 PC is used as the digital active processor. This model was chosen primarily for cost reasons.

Figure 12: ALTO Maxidrive 3.4 PC

The Maxidrive offers enough parametric equalizers for each output for a sufficiently accurate equalization of the individual branches. Furthermore, five parametric equalizers are available per input, which can be used for possible room equalization. The slope of the Linkwitz-Riley filters is adjustable up to 48 dB/oct.

3 Measurements

3.1 Measurement setup

Since the adjustment of the active crossover is only possible if exact measurement results of the drivers are available, all measurements were carried out in a gym. Due to the room size, this has the advantage that the reflections of the walls arrive at the microphone very late and can therefore easily be hidden by setting a window in the impulse response.

Figure 13: Measuring arrangement with measuring distance of 3 m

The reflection from the ground was delayed by a measurement at a high altitude (2.5 m). In Figure 14 it can be seen that the first reflection from the ground arrives after about 8 ms, which corresponds to 2.7 m.
To ensure that the individual ways overlap each other as in later use, the loudspeaker was measured in the far field. The microphone was located at a distance of 3 m.

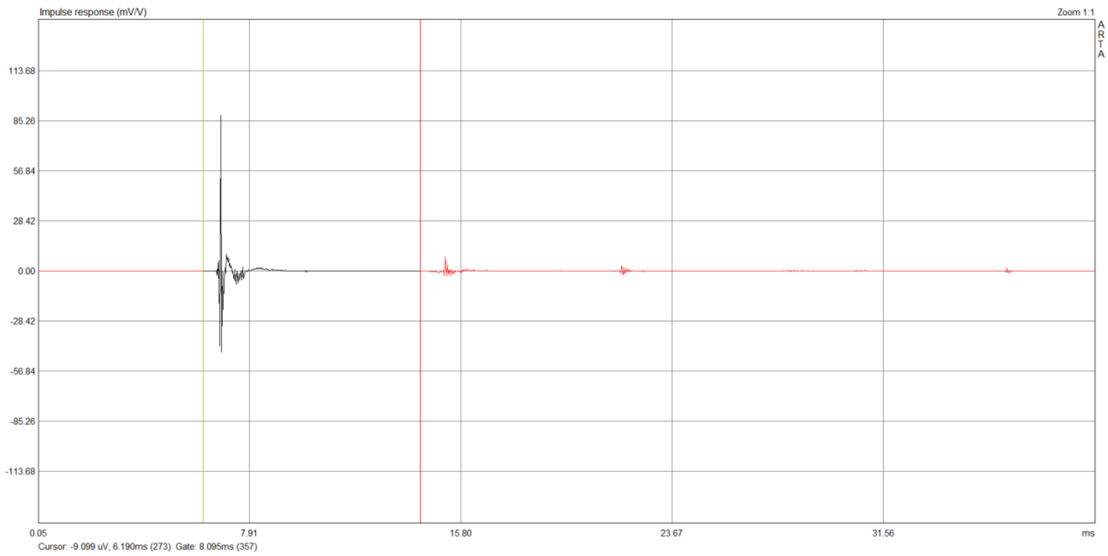

Figure 14: Impulse response with window

Measurements were taken with ARTA 1.7. A calibrated IMG STAGE LINE ECM-40 was used as the microphone.

3.2 Amplitude Response

First, the individual ways were measured and the amplitude responses were equalized an octave beyond the desired crossover frequency using a parametric equalizer. The curves are smoothed by 1/24 octave.

In the amplitude response of the tweeter (Figure 15), interference patterns due to edge diffractions can be seen. However, since the speaker is to be installed in a wall later, this has no significance.

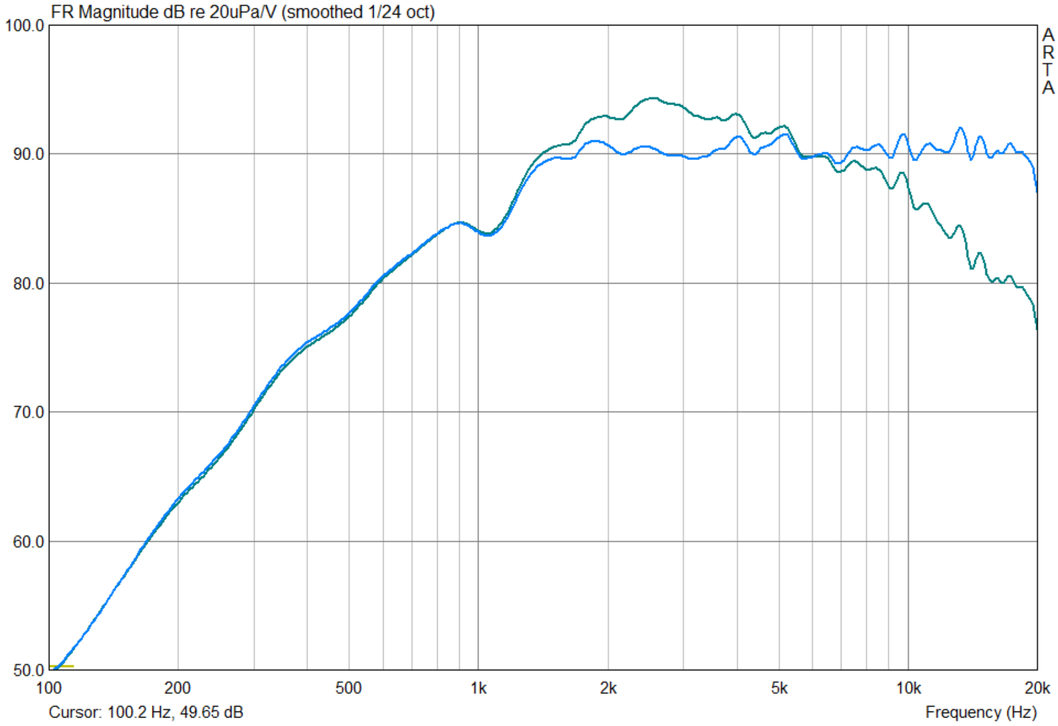

Figure 15: Tweeter equalization

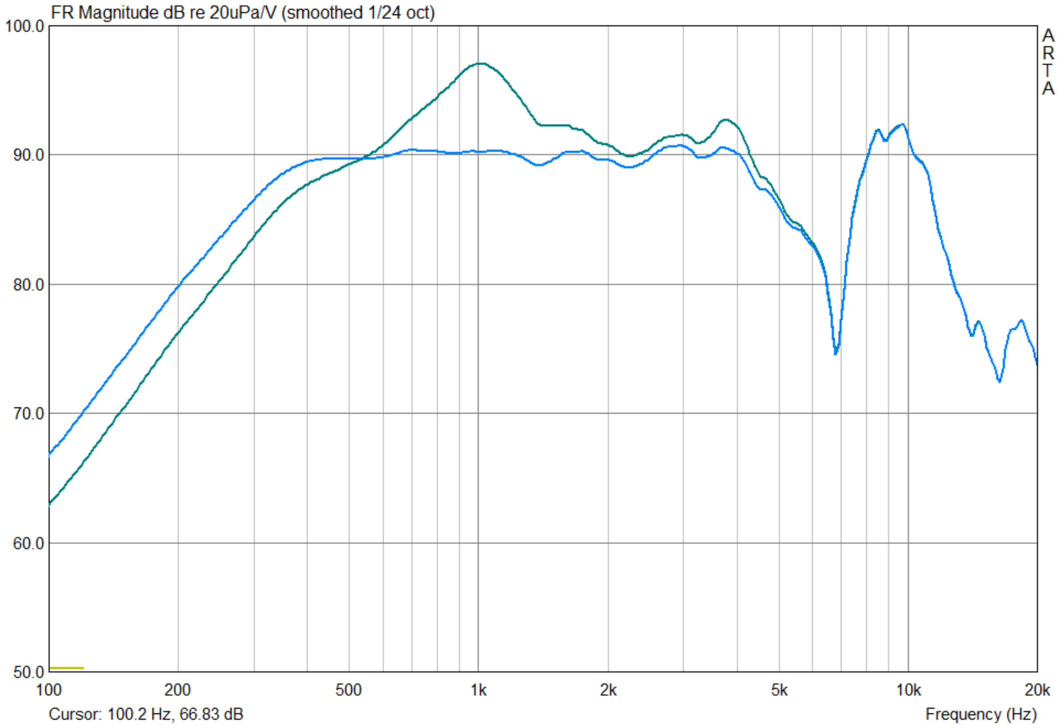

Figure 16: Midrange equalization

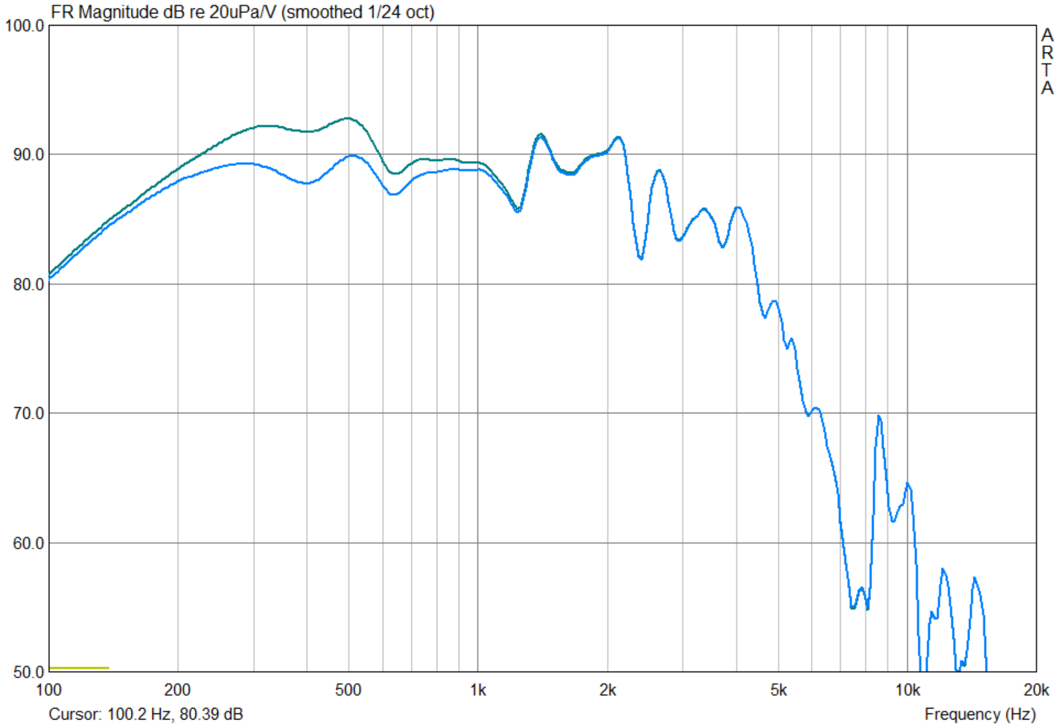

Figure 17: Equalization of the midwoofer driver

After equalization, the target functions were specified and the gains were adjusted so that all ways had the same level. Since the sound origin locations (SEO) of the midwoofer, midrange and tweeter are almost in the same plane, only minor delays were necessary. The slope at 2400 Hz was later increased from 24 to 48 dB/oct to minimize interference between midrange and tweeter.

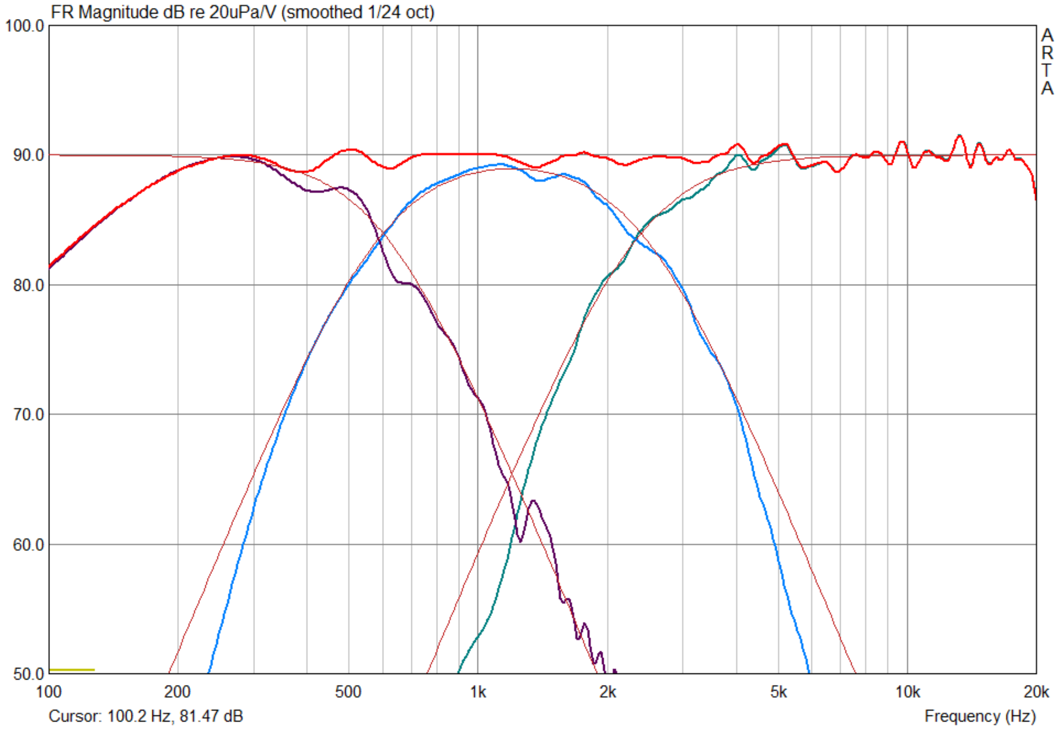

Figure 18: Amplitude responses

The drop in the midwoofer's response at 200 Hz was deliberately not equalized, as the subsequent wall installation has a massive influence on the dispersion and thus also on the amplitude response. The equalization in this area takes place directly in the room.

3.3 Phase Response

Figure 19 shows the unsmoothed phase response. As expected from the filter steepness of 24 dB/oct and 48 dB/oct, there is a 360° and 720° phase rotation in the crossover frequency range. The phase rotation at the upper end of the transmission range is caused by the steep low-pass in the D/A converter of the digital active crossover.

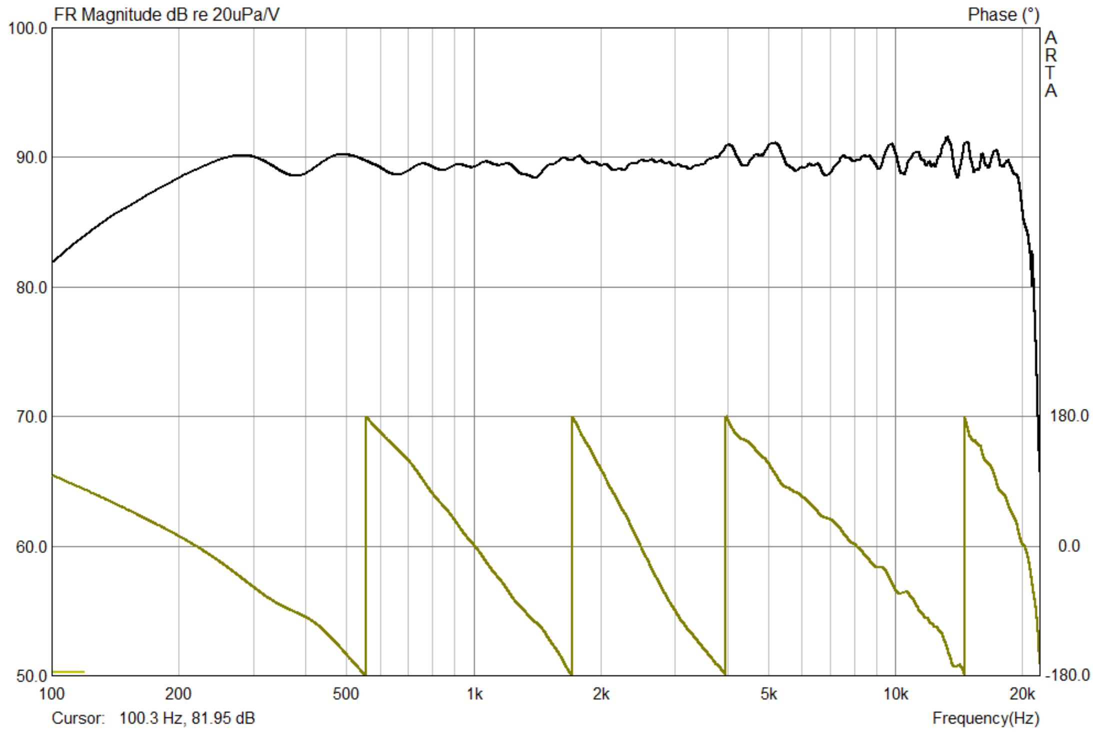

Figure 19: Amplitude and phase response (unsmoothed)

The group delay is below the perception threshold over the entire frequency range.

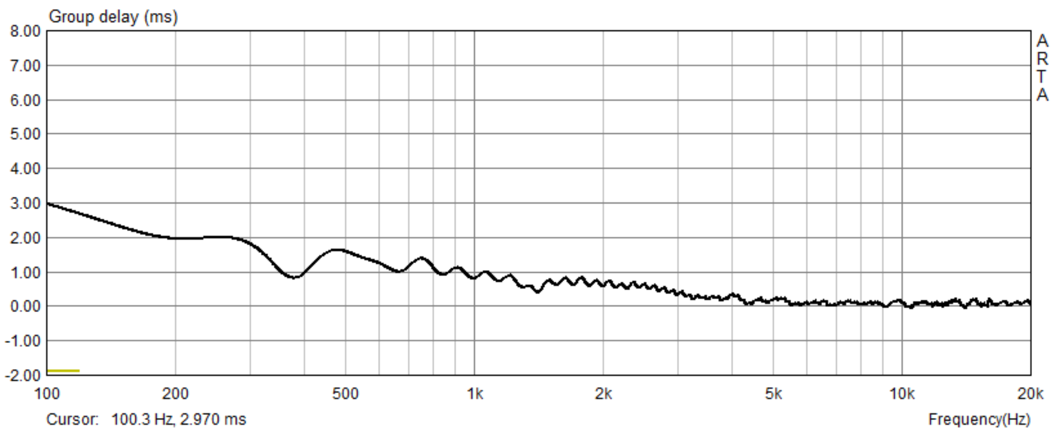

Figure 20: Group Duration

3.4 Dispersion

As expected, the horizontal dispersion is relatively constant in the range of 700 – 17,000 Hz. In addition, it is completely free of fluctuations. The beam angle is approx. 100°. As expected, the midwoofer radiates wider.

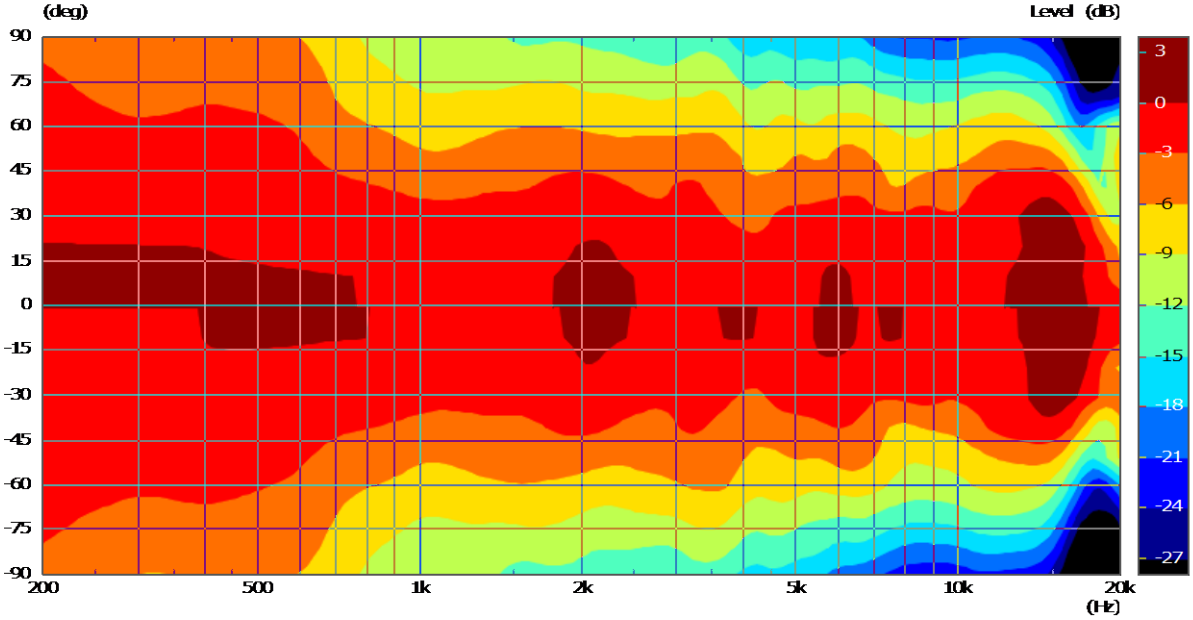

Figure 21: Horizontal dispersion

The directivity index also shows the steady behavior with low fluctuations.

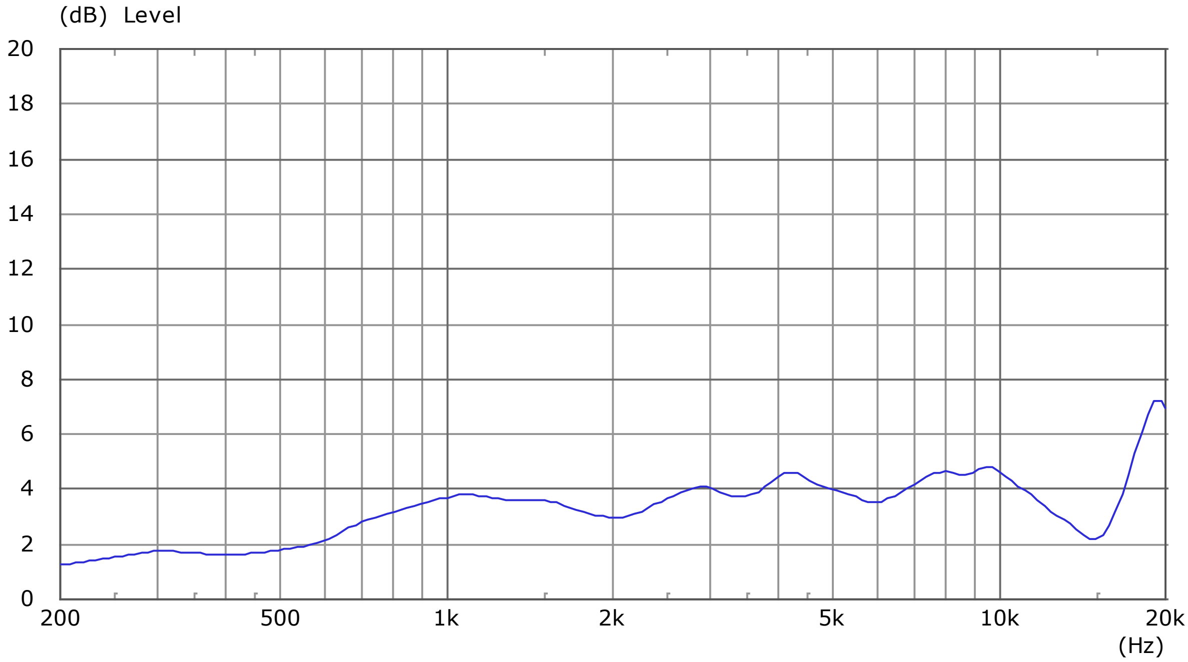

Illustration 22: Directivity index (half cylinder related)

3.5 Nonlinear distortions

The following measurements were subsequently carried out with the Audix TM-1 measurement microphone in a smaller room, as this has significantly lower distortion than the previously used ECM-40.

The non-linear distortion is very low, especially in the important midrange. Even at 100 dB, K2 remains below 0.5% in a wide frequency range. K3 is almost non-existent in the midrange and treble. It is pleasing that the slightest distortion occurs in the sensitive midrange.

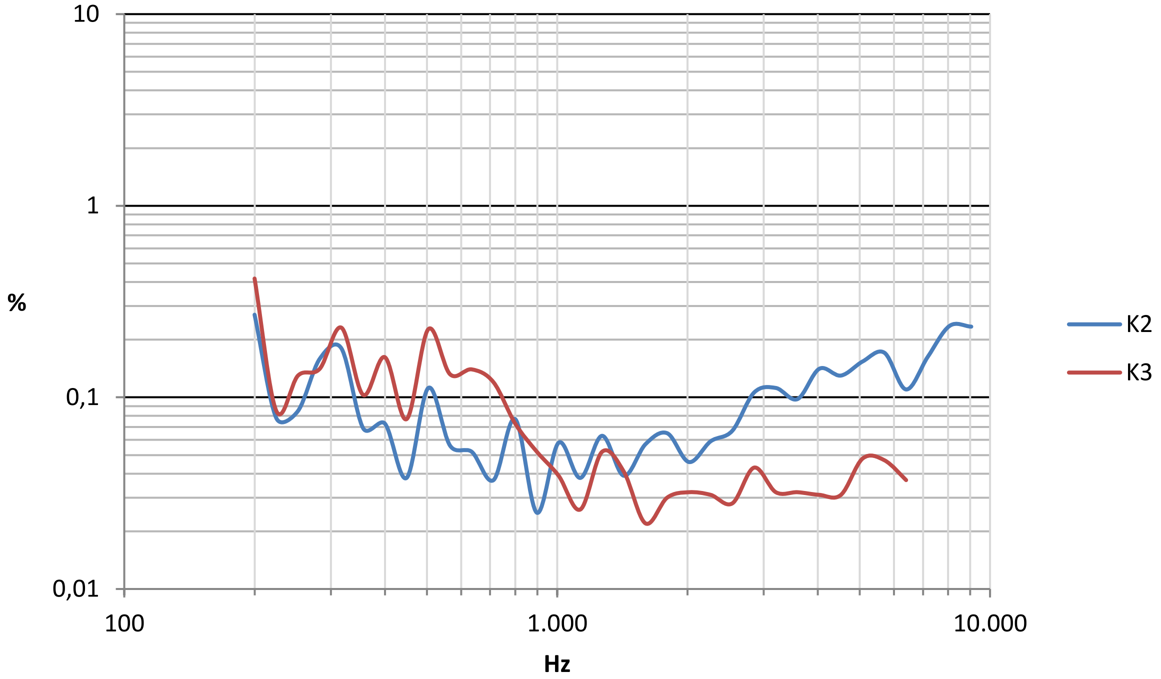

Figure 23: Nonlinear distortion at 90 dB

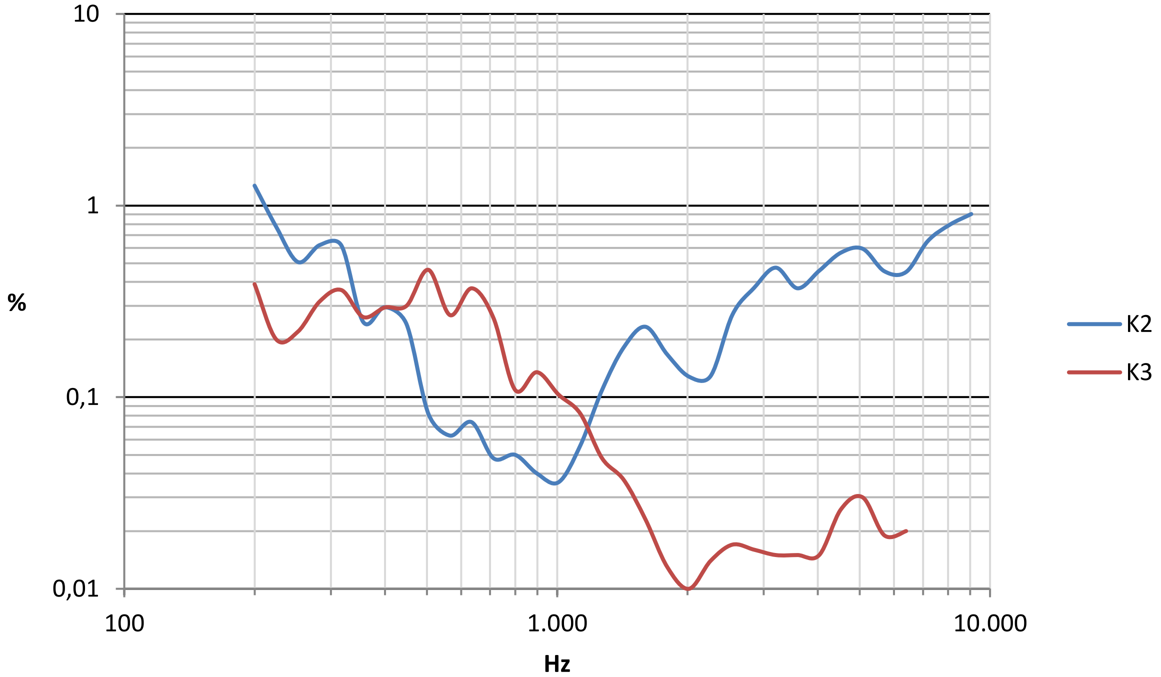

Figure 24: Nonlinear distortion at 100 dB

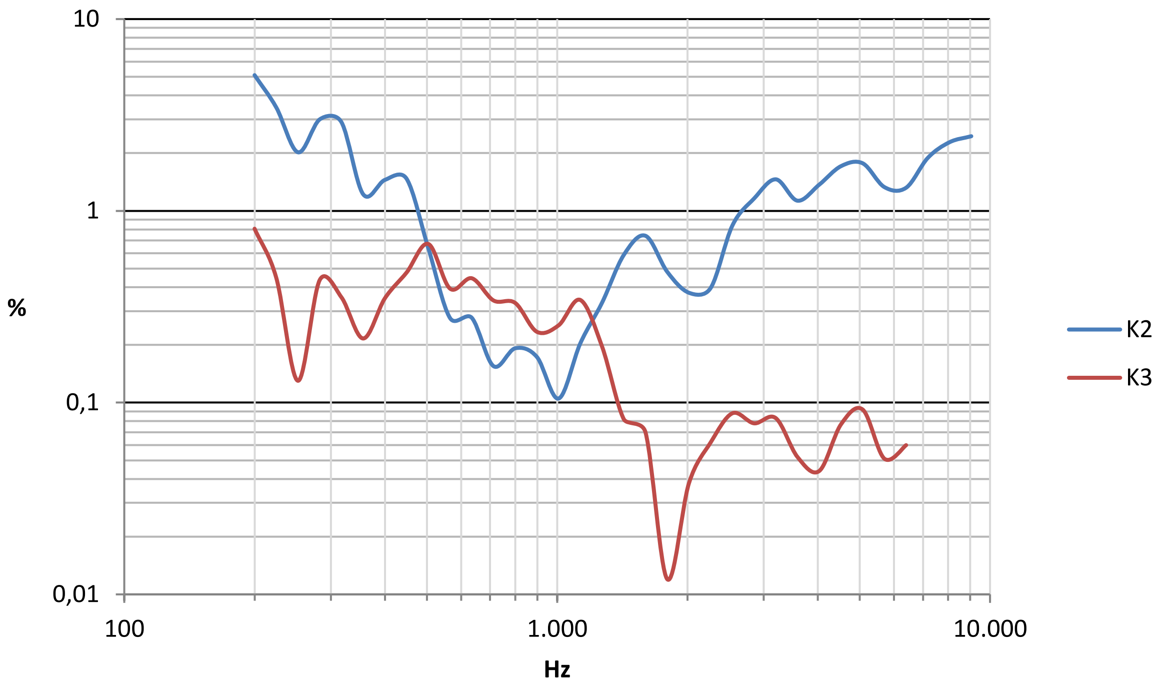

Figure 25: Nonlinear Distortion at 110 dB

3.6 Decay Spectrum

In the cumulative decay spectrum (CSD), no significant resonances can be detected. The enclosure is sufficiently damped.

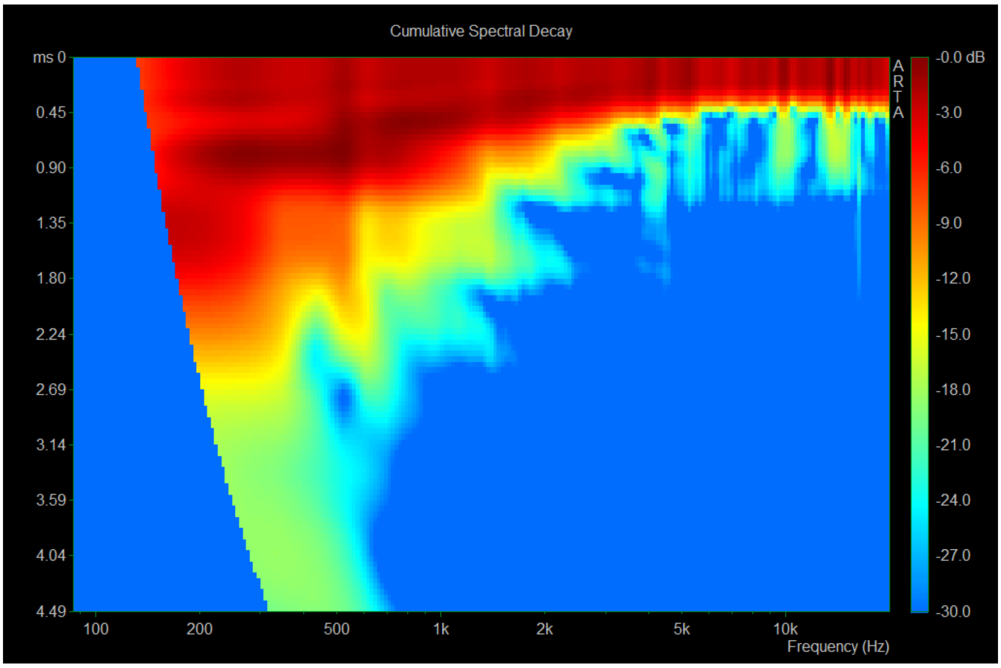

Figure 26: Cumulative decay spectrum

4 Specifications

Free Field Transmission:		200 Hz – 20 kHz, ± 1.5 dB
Horizontal beam angle:		100° @ 1 – 15 kHz
Distortion factor:	< 0.3% in 1 m	1 kHz @ 100 dB SPL
Analog inputs:	Active crossover:	1 x XLR Balanced
	Power amplifier:	3 x XLR Balanced
	Loudspeaker:	speakON 8-pin
Midwoofer:		300 mm Cone loudspeaker
Midrange:		75 mm dome
Tweeter:		26 mm dome
Crossover frequencies:		100 Hz (24 dB/oct)
		600 Hz (24 dB/oct)
		2400 Hz (48 dB/oct)
DAC/ADC:		20 bit, 48 kHz
Internal Accuracy:		40 bit
Equalizer:		5 x IIR filters for room adjustment
Amplifiers:		3 x 180 W RMS @ 4 Ω
Dimensions:		670 x 330 x 170 mm (H x W x D)