Quasikoax 1 Documentation

Content

Motivation

The aim of the development is to create a free-standing loudspeaker that has a horizontally wide and vertically narrow dispersion characteristics. Lateral reflections should therefore be deliberately retained so as not to negatively impair the spatiality, envelopment and timbre. In order to achieve the best possible imaging and localization, the loudspeaker should focus strongly vertically. This attenuates reflections on the floor and ceiling.

Furthermore, the aim was to avoid the use of deep waveguides and thus horn modes in the transmission range as far as possible. The speaker should not exceed a certain maximum size.

Requirements

The aim of the development was to create a loudspeaker with the following features.

Acoustic requirements:

1. Operation together with a subwoofer system which is crossed at approx. 100 Hz
2. Free-standing installation (no wall mounting)
3. Horizontal wide dispersion to ensure spatiality and envelopment
4. Vertically narrow dispersion to reduce floor and ceiling reflection and to produce a good ratio of direct and diffuse sound over longer distances
5. Acoustic center frequency-independent at one point
6. High undistorted maximum sound pressure

Enclosure size requirements:

1. Maximum depth of 40 cm
2. Maximum width of 40 cm
3. The height is limited only by the dimensions of the room

The maximum cost of the project was not limited in a way that the acoustic properties had to be severely restricted.

The speaker should be fully actively controlled. This has enormous advantages especially regarding the filter function and equalization of a multi-way speaker. Linear-phase FIR filters are to be used.

Development

Procedure

The development of the loudspeaker can be divided into the following steps:

1. Creating a concept and evaluating it via BEM
2. Measure and select suitable drivers
3. Adapt the model to a specific driver selection and optimize it iteratively via BEM
4. (simplified) building and measuring of prototypes
5. Make adjustments if necessary

This approach has the advantage that a large part of the optimization is already carried out on the computer, thus keeping the number of prototypes low. This reduces the cost of the project and ensures that an optimal baffle geometry is found as early as possible.

Concept

The horizontal and vertical dispersion characteristics of a loudspeaker can usually be considered independently of each other. This simplifies the problem and allows both dimensions to be optimized separately within certain limits. This principle was used to develop this speaker.

Arrangement of drivers

As a concept, the choice fell on a 3-way speaker with an optimized arrangement of midrange drivers around a single tweeter. The interference between the midrange drivers causes a narrowing of the horizontal and vertical dispersion behavior. At the same time the distances between the drivers within a way are chosen in such a way that sidelobes only occur above their transmission range. Due to the overlapping of the ways beyond the crossover frequencies, the directivity is kept constant.

The spacing of the drivers within a way is particularly important in this concept. This distance should be as small as possible in order to move sidelobes outside the designated frequency range. Sidelobes occur when the wavelength is in the range of the distance between two driver centers.

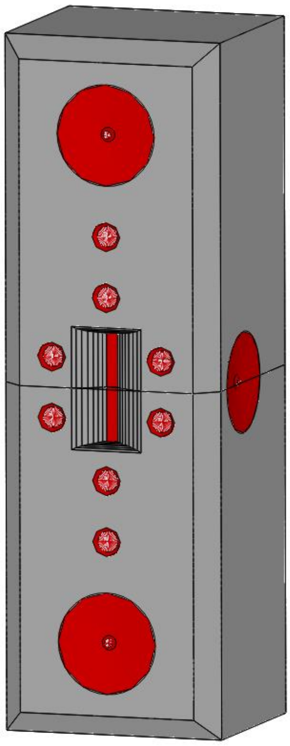


Figure 1 - 3D Model of the Speaker

After various optimizations the following diaphragm diameters, distances and dimensions of the overall arrangement have proven to be a good compromise.

	Diaphragm size (cm)	Horizontal dimension (cm)	Vertical dimension (cm)	Horizontal distances (cm)	Vertical distances (cm)
4 x Woofer	17	31	70	15	35
8 x Midrange	5	15.7	42	5.2	8.4
1 x Tweeter	14.5 (length)	10 (Waveguide)	17 (Waveguide)	-	-

The side woofers and midrange drivers emit only half the sound level, i.e., they are weighted with 0.5. This results in a vertical sum of 1 for each row. Horizontally, on the other hand, the center column has four times the weight of the two outer columns. This contributes to the wide horizontal radiation.

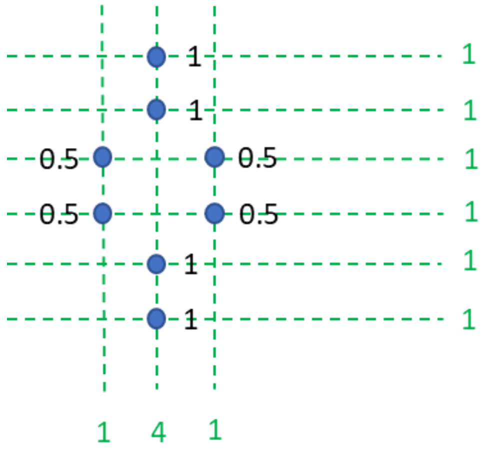


Figure 2: Weighting of the individual midrange drivers

The overall size of a ways' driver array determines the strength of its directivity. That's why the height of the woofer and midrange arrays are significantly larger than their width. The side woofers are a compromise made in favor of cabinet width. However, in the overlap area with the front-mounted woofers, they generate a significant directivity in the rear and front hemispheres. Since they require a different delay than the front-mounted woofers, an additional DSP channel is needed.

Although the arrays are vertically close to a line source, they are too short to produce a cylindrical wave at the listening position in their frequency ranges. This also means that listening is always done in the far field and the sound pressure level decreases by 6 dB per doubling of distance. The disadvantage of a distance-dependent amplitude response, which is inherent in line sources, is therefore not present.

The speaker has the following dimensions:

- **Width: 31 cm**
- **Height: 100 cm**
- **Depth: 28 cm**

This yields in a relatively compact speaker with respect to the strength of the directivity and its lower cut-off frequency. Various different and related concepts were simulated using BEM. For example, the extension of the vertical directivity to low frequencies through a greater length of the woofer arrangement. However, this did not bring much improvement compared to the additional effort. One reason for this is that the significantly wider horizontal dispersion is dominant in the directivity index and thus changes to the narrow vertical have hardly any effect.

Crossover frequencies

The filters used were linear phases of type Horbach and Keele [1] and Linkwitz/Riley. The difficulty with this concept is that the crossover frequencies affect both dimensions of the dispersion. The following crossover frequencies turned out to be optimal.

	High-pass (Hz)	Low-pass (Hz)	Bandwidth in octaves
Woofer	100	600	2,5
Midrange	600	2.000	1,8
Tweeter	2.000	-	3,8

The tweeter must reproduce the widest bandwidth. However, its crossover frequency is not that low that the real driver candidates would cause problems.

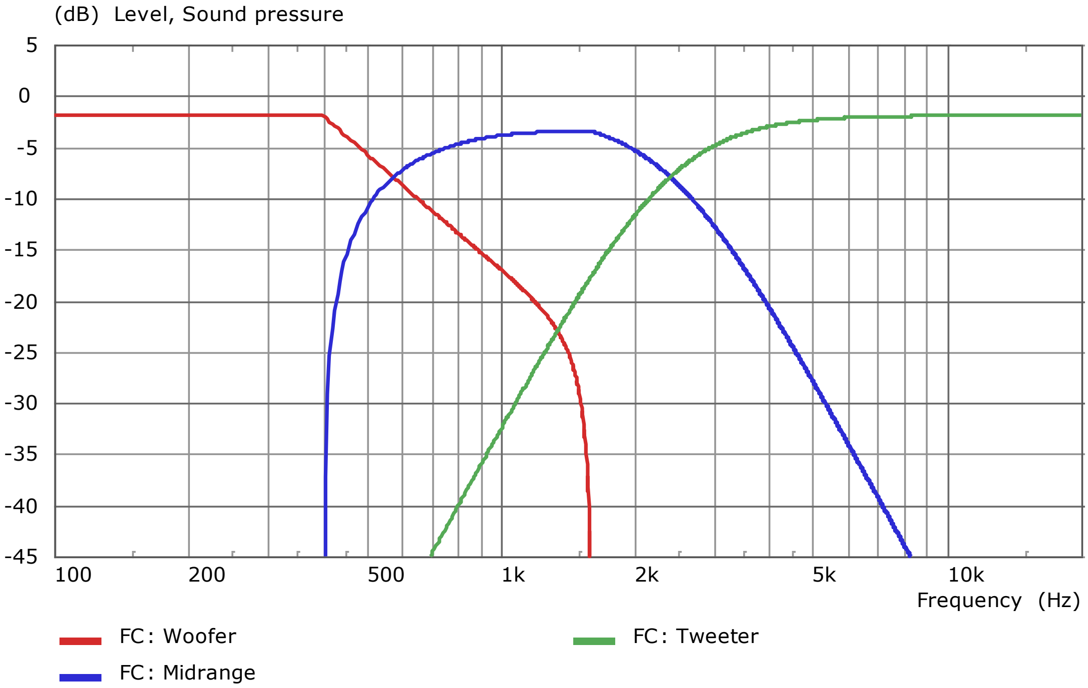


Figure 3: Crossover filtering functions

Waveguide

While the vertical dispersion in the tweeter is generated by the large expansion of the diaphragm, the horizontal dispersion had to be realized by a waveguide in order to form it as constant as possible and not too wide. Initially, a simple waveguide exclusively for the tweeter was simulated and optimized using BEM.

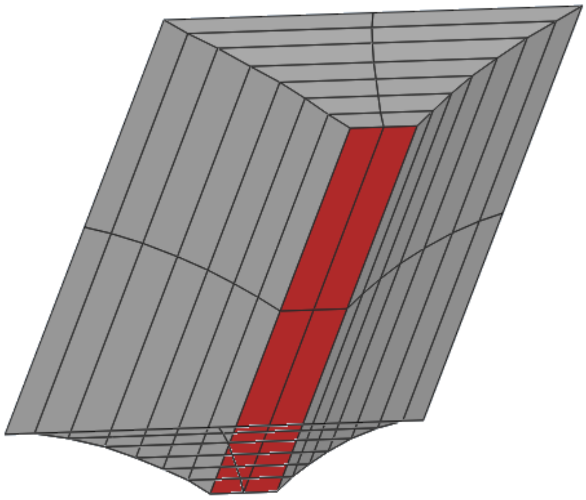


Figure 4: Simple model of waveguide

Once the optimal contour for that waveguide was determined, it was embedded in the complex 3D model for the entire loudspeaker and iteratively optimized using the BEM simulator. The waveguide has been optimized so that the beam angle at -6 dB is approx. 120°.

Other properties

The 4-way plus subwoofer concept automatically meets the rest of the acoustic requirements. Since there are multiple drivers in each way except for the tweeter, the maximum level increases compared to a single driver. At the same time, this reduces the non-linear distortions. The tweeter already fulfills this with its very large diaphragm area.

In addition, since the ways are only used in limited frequency bands, the particularly harmful intermodulation distortions are significantly reduced.

Finally, the quasi-coaxial arrangement of the drivers creates a frequency-neutral localization from the direction of the tweeter. The loudspeaker is thus similar to a coaxial system.

Results of the simulation

From approx. 500 Hz, the horizontal dispersion changes to an almost constant characteristic. Slight sidelobes occur in the rear hemisphere at about 700 – 900 Hz. The fact that the directivity is still so narrow there is due to the overlap between the front and the side woofers.

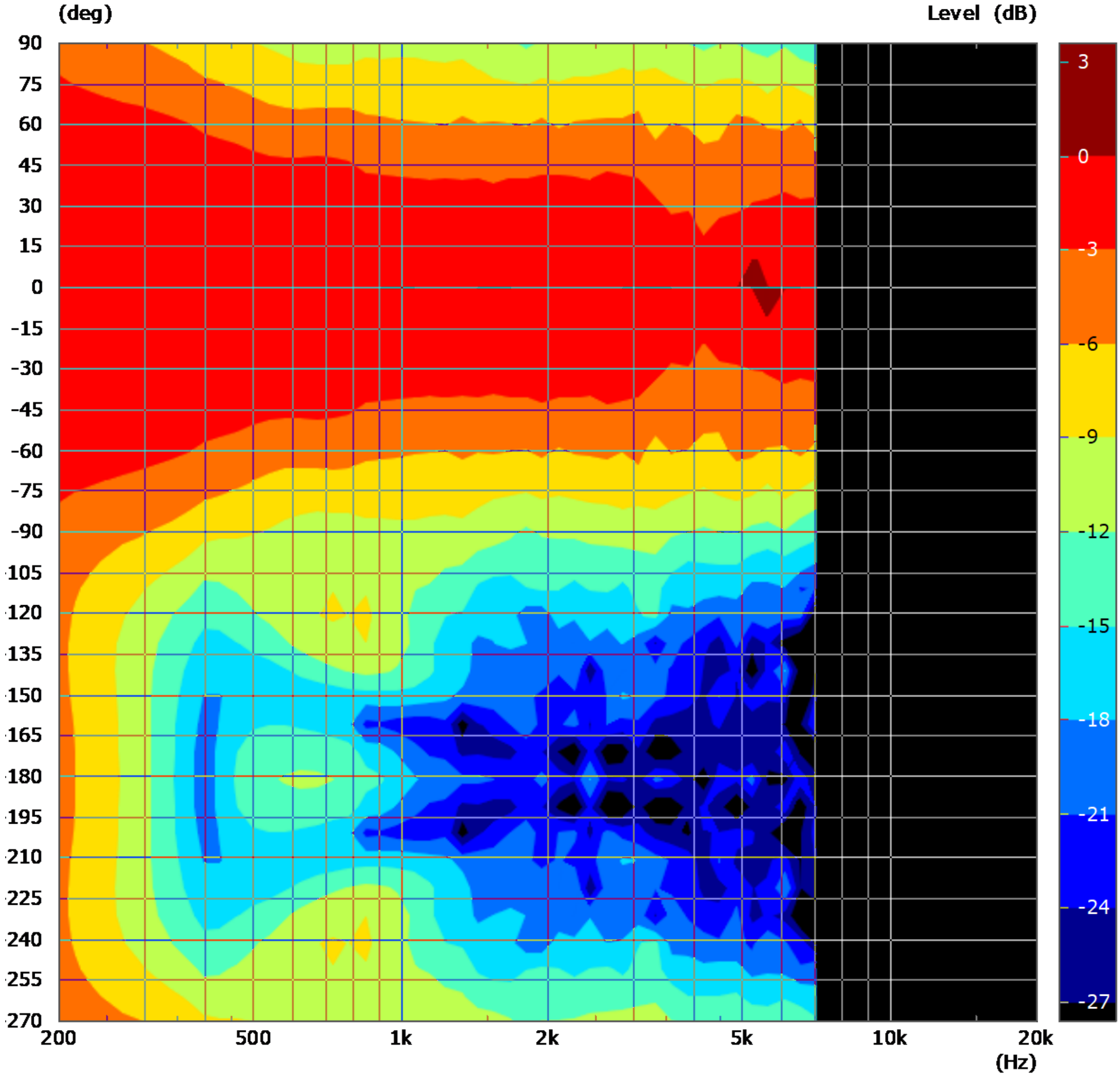


Figure 5: Horizontal dispersion behavior of the simulation

The vertical dispersion has been optimized to approx. 30° and shaped as constant as possible through a clever selection of crossover frequencies. From approx. 900 Hz, the directivity reaches its setpoint and increases from approx. 6 kHz. At 4 kHz, there is a slight expansion. Sidelobes are sufficiently attenuated.

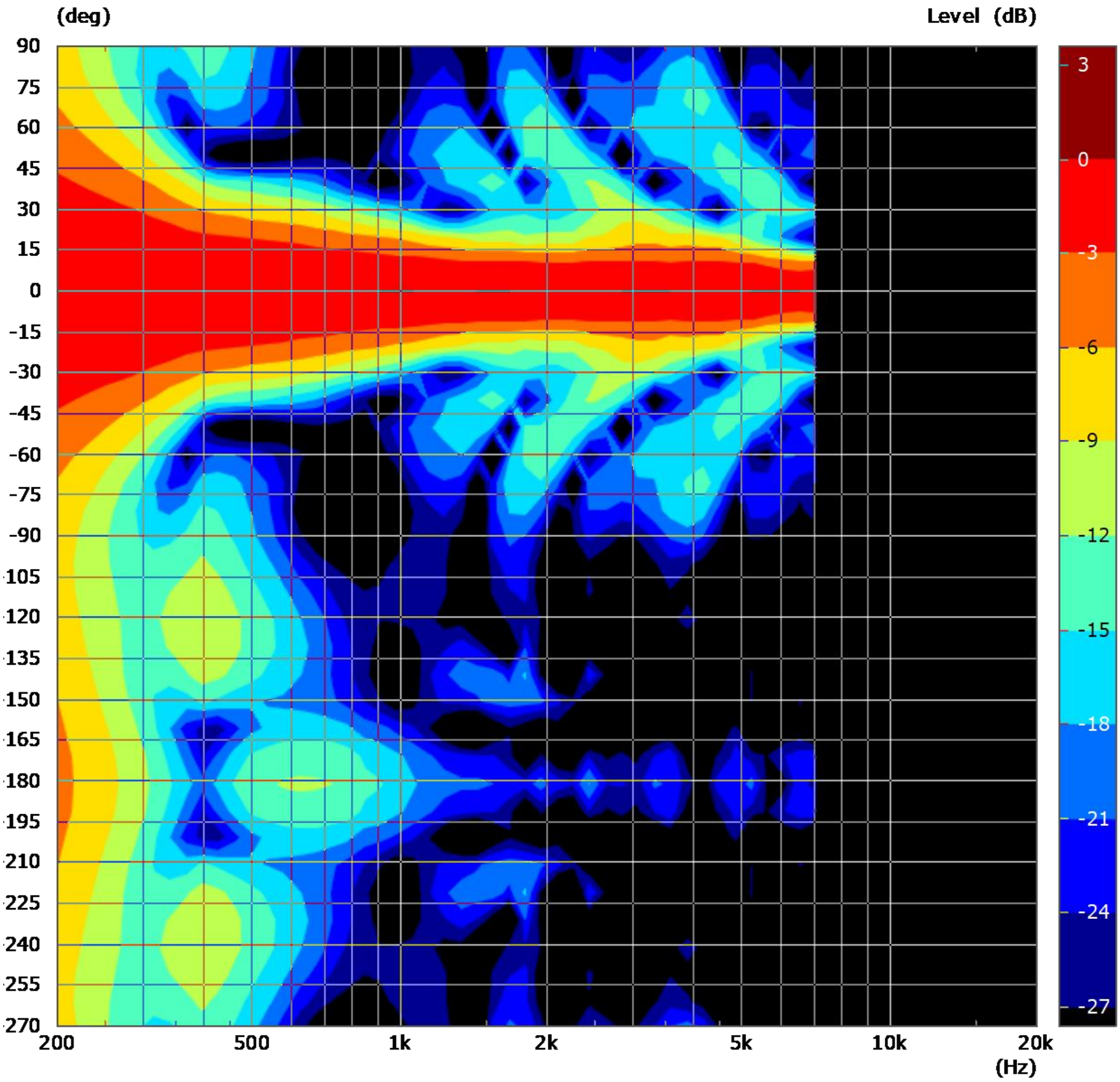


Figure 6: Vertical dispersion of the simulation

The fact that sidelobes are strongly attenuated horizontally and vertically does not mean that this must also be the case vertically. Especially with rectangular drivers, diagonally is usually no longer so good-natured. However, through optimizations, it has been possible to reduce the sidelobes to approx. -10 dB in these directions as well.

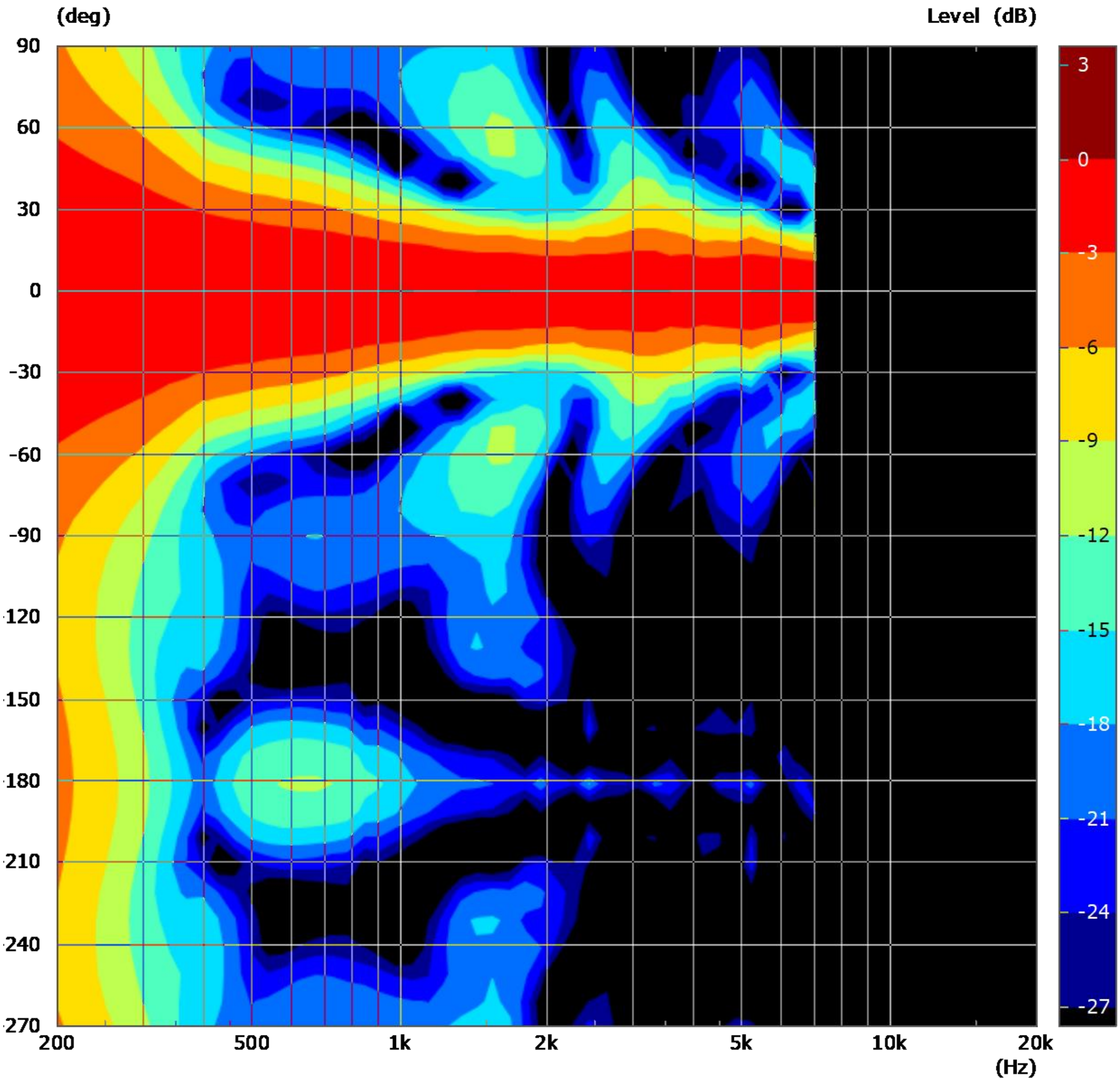


Figure 7: Diagonal dispersion

The sphere-based directivity index which was calculated from the horizontal and vertical dispersion behavior [2], is almost constant from 900 Hz and increases only minimally. Even from about 500 Hz, it is still relatively high, which reflects the high directivity.

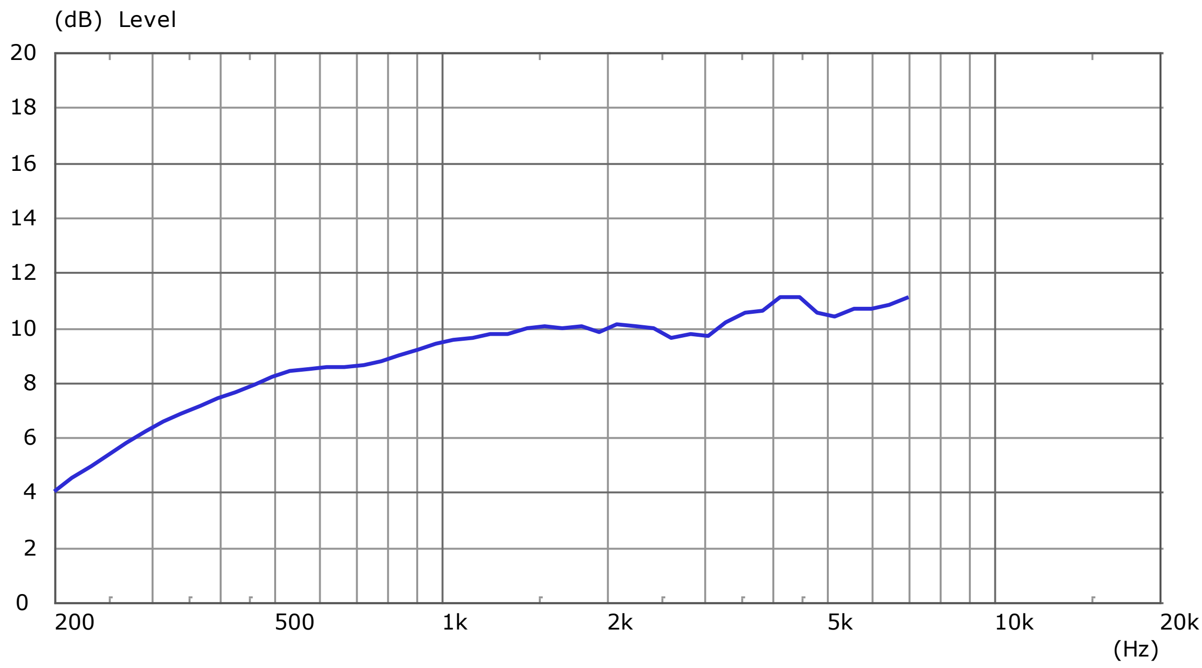


Figure 8: Sphere-based directivity index

Manufacturing

Transducers

The following drivers were selected for the final product, most of which were already defined during computer-aided optimization due to their dimensions. In total, almost 20 different models were measured and evaluated.

- Woofer: SB Acoustics SB17NRXC35-8
- Midrange: Aurasound NSW2-326-8AT
- Tweeter: Dayton AMTPRO-4

In the case of the woofers, low non-linear distortion and good oscillation characteristics were the main criteria for selection. The SB17NRXC35-8 has these characteristics.

The midrange drivers had to be particularly small to ensure the small distance to the tweeter. This restricted the selection considerably and practically only 2" full-range bands remained. The choice fell on the Aurasound NSW2-326-8AT, which has a very small mounting bezel and can be easily mounted from the back in a solid baffle. A damped rear chamber was mounted on each of these drivers. The low SPL of each driver is compensated by the large number.

The Dayton AMTPRO-4 was chosen as the tweeter, which has a very good price-performance ratio for an AMT and also the right length and width for the concept. The AMT is installed in its own volume, as it does not have a rear chamber.

Construction

The enclosure has been developed with a 3D CAD software and specifically designed with the selected drivers in mind, allowing for flush mounting without gaps or protruding parts.

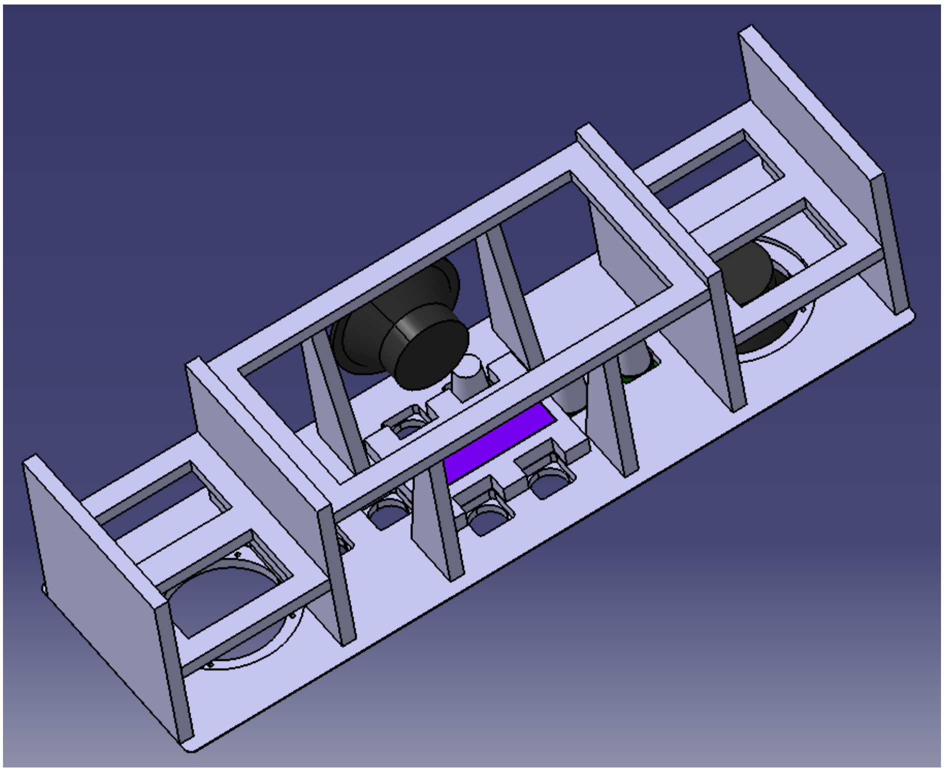


Figure 9- Interior structure of the loudspeaker

The front was completely CNC machined from a plastic block. This has the positive side effect that the massive part has no problems with resonances in the transmission range. In addition, several stiffeners were provided in the enclosure.

Subsequently, the baffles were painted matt black. This is supposed to create a visual contrast to the bright enclosure made of maple plywood.

Figure 10: Front of the baffle

Figure 11: Back of the baffle

Since the Aurasound NSW2-326-8AT is an open driver design, a suitable rear chamber was sought. Shatterproof shot glasses made of plastic have proven to be suitable and sufficiently stable. These were filled with Caruso Iso Bond and glued to the back of the midrange drivers. As a positive side effect, the resonance created by the rear opening of the driver is effectively dampened.

The off-centered midranges are weighted at 0.5, which means that they only have to produce half as much sound level as the vertically centered ones. Since, in contrast to the side woofers, no additional delay was necessary, the weighting could be achieved by means of an additional series connection.

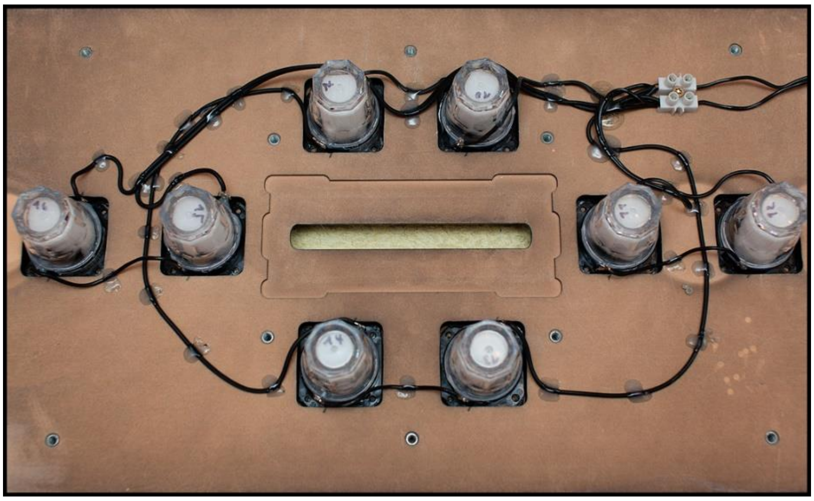


Figure 12: Built-in midrange drivers

All cables have been fixed in the housing with hot glue so that they cannot vibrate and create interfering noise.

Figure 13: Connected baffle

Since the tweeter has a wide surface area of 38 mm, the waveguide has been designed to cover part of this area from the sides. This was the only way to achieve the desired horizontal dispersion in the highs.

Figure 14: Waveguide

The case is made of plywood with maple veneer. The side walls were mitred and the edges were milled round so that they are less sensitive to impacts later. Subsequently, the case was sanded twice and varnished with semi-gloss parquet varnish.

Figure 15: Gluing the enclosure

Figure 16: Rounded edges

Since the midranges and tweeter were recessed into the front from the rear and no screws should be visible, the front was screwed to the cabinet from the rear. As a result, the back panel had to be removable.

The 8-pin speakOn jack is firmly attached to the case and is accessible through an opening in the rear panel.

Figure 17: Rear panel with speakOn jack

The inside of the enclosure has been completely filled with Caruso Iso Bond WLG 045 to dampen standing waves.

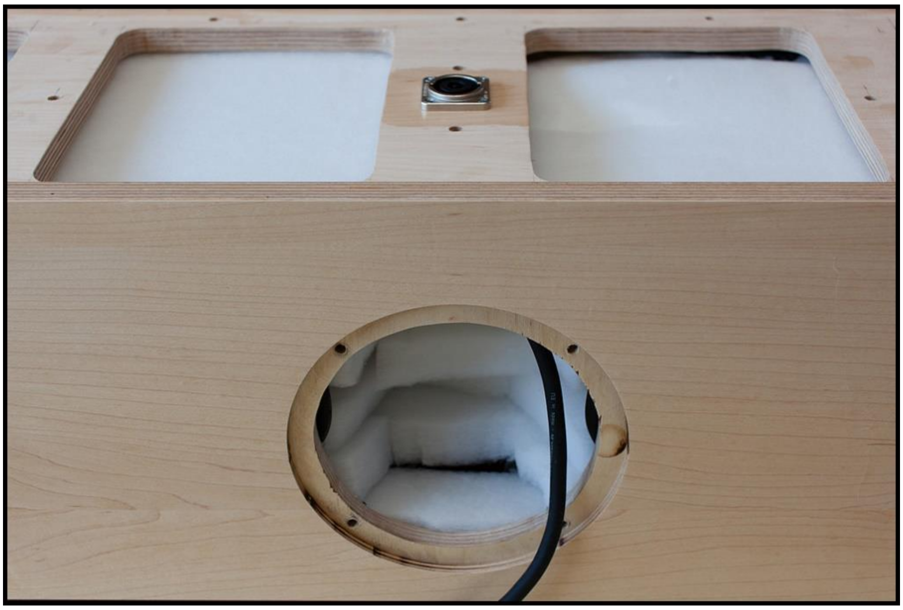


Figure 18: Filling with Iso Bond WLG 045

Measurements

In order to measure the loudspeaker in an environment that was as reflection-free as possible, it was placed on a tripod in the garden. The first reflection from the ground arrives at the microphone about 7 ms after the direct sound. This allows for a sufficient window length when evaluating the impulse response.

Figure 19: Measurement in the garden

Amplitude and phase response

Both the amplitude and phase response were linearly equalized. An adjustment to the listening room is also made, but only the bass and lower midrange are equalized.

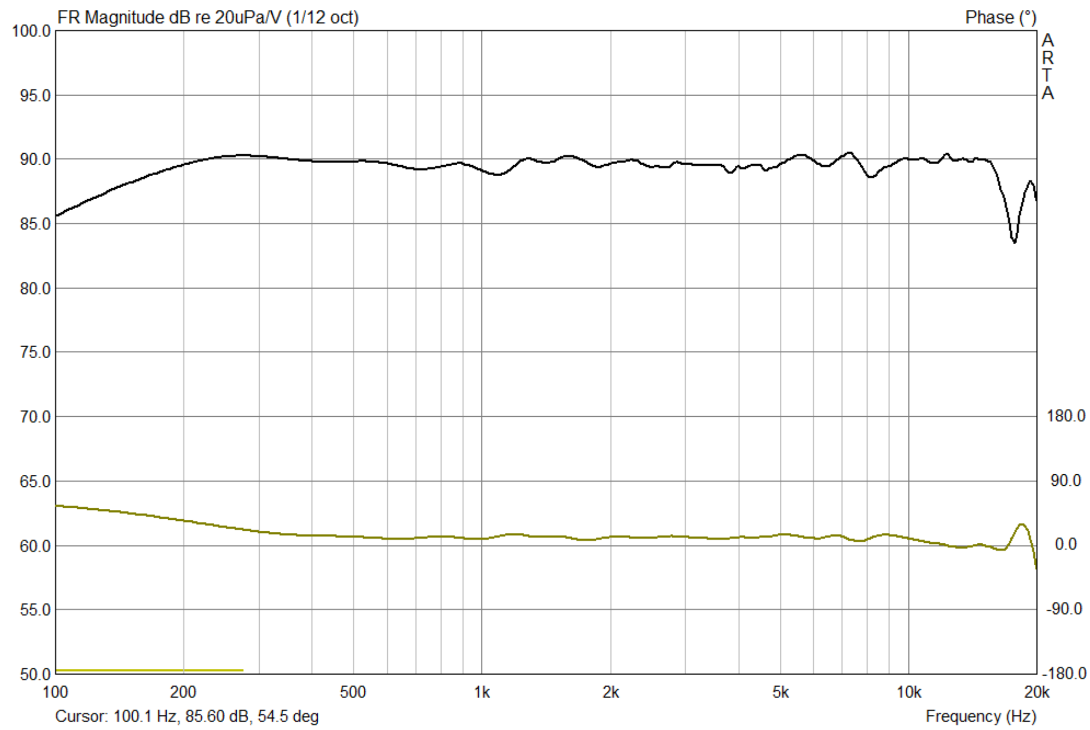


Figure 20: Complex frequency response

Nonlinear distortions

The nonlinear distortions are low overall and below the threshold of perception. In the midrange, K3 is slightly elevated, which is due to the midrange drivers. This was accepted in advance for cost reasons and because the drivers could be installed from the back.

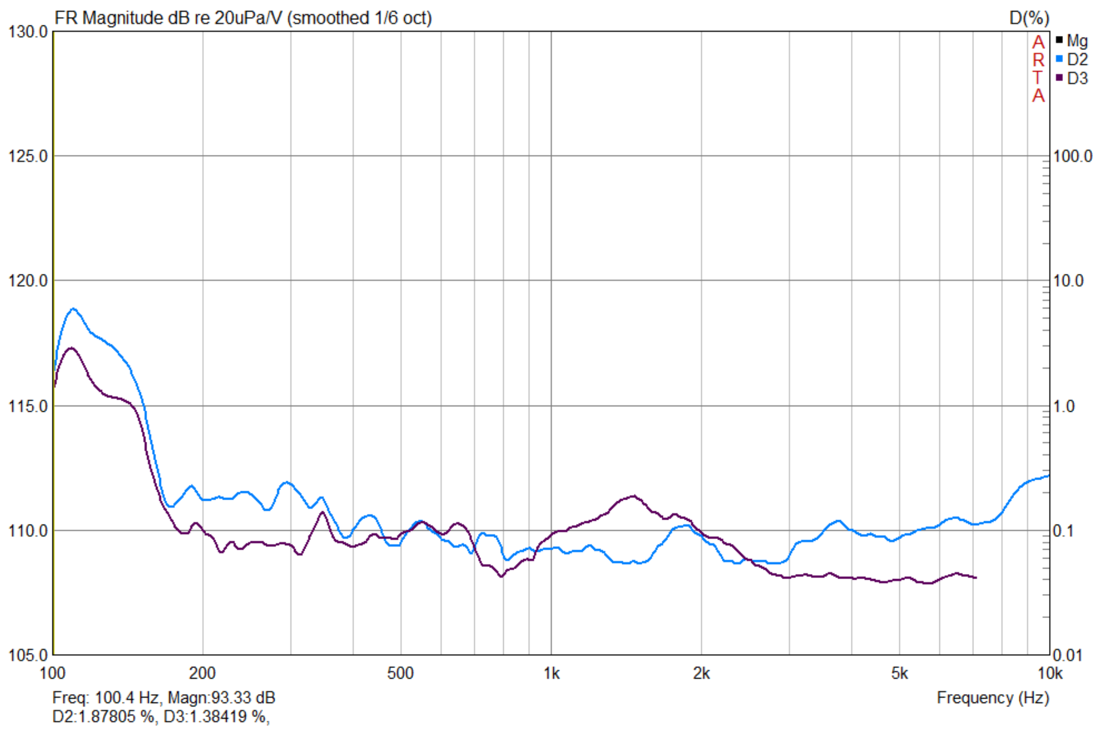


Figure 21: Nonlinear distortion at 100 dB

Decay Spectrum

Overall, the decay spectrum is inconspicuous. There are still attenuated resonances of the tweeter visible, which should fall into the inaudible range.

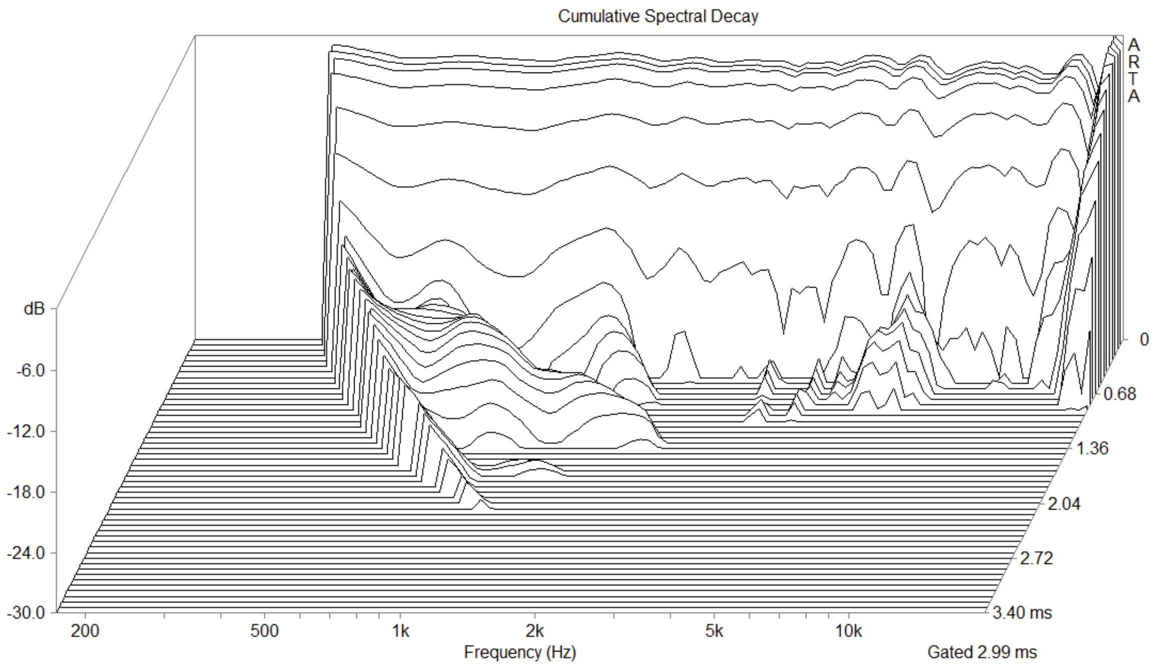


Figure 22: Decay spectrum

Dispersion

The horizontal dispersion deviates only slightly from the simulation. It depends a lot on the filtering functions and the equalization of the individual branches, so a lot of time had to be invested in the tuning here. The targeted beam angle of 120° (-6 dB) is maintained over a wide frequency range.

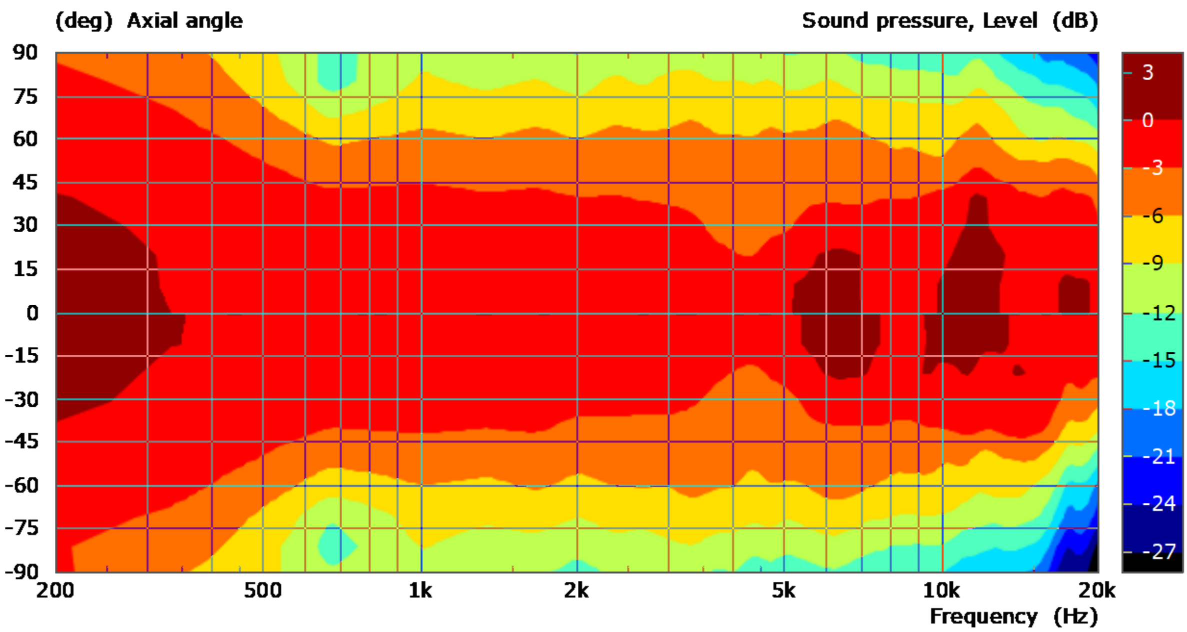


Figure 23: Horizontal dispersion

Vertically, there are no surprises. The dispersion behavior is largely the same as the simulated one. Significant sidelobes are absent.

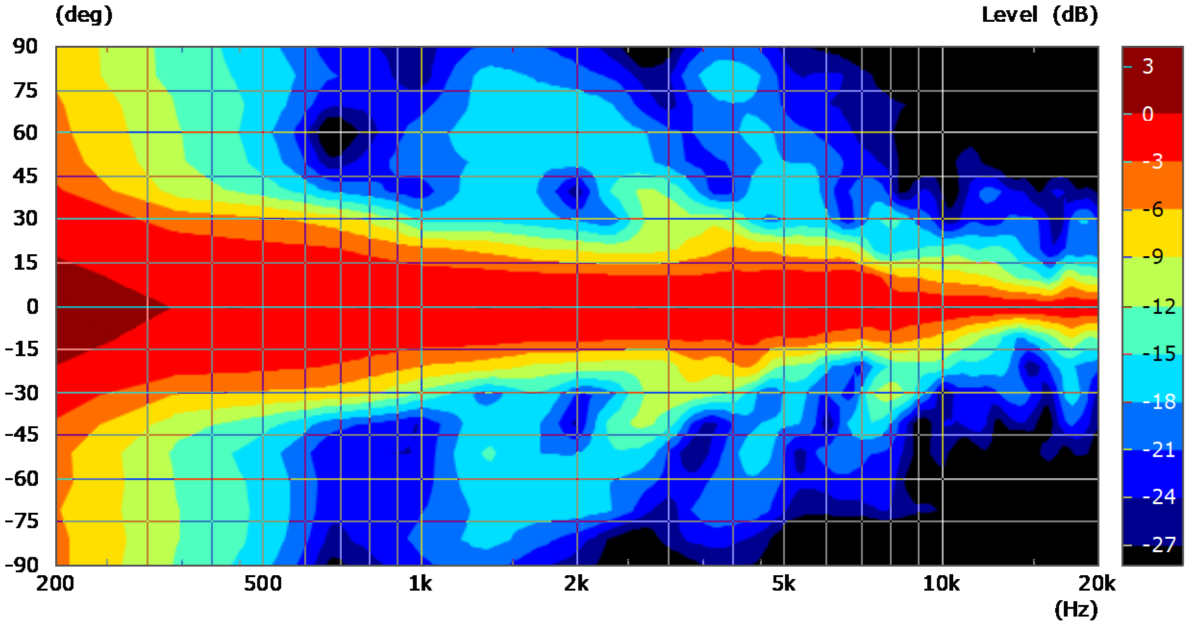


Figure 24: Vertical dispersion

The sphere-based directivity index, which was calculated from the horizontal and vertical dispersion behavior, is almost constant between 600 Hz and 12 kHz and fluctuates by just ± 0.6 dB.

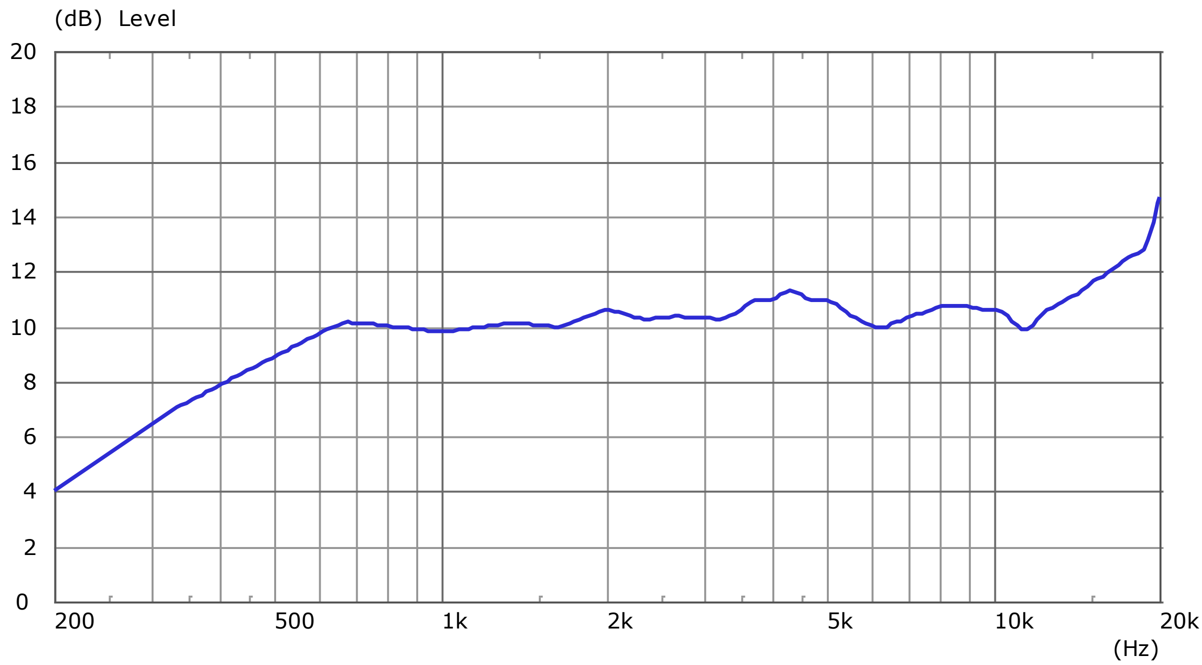
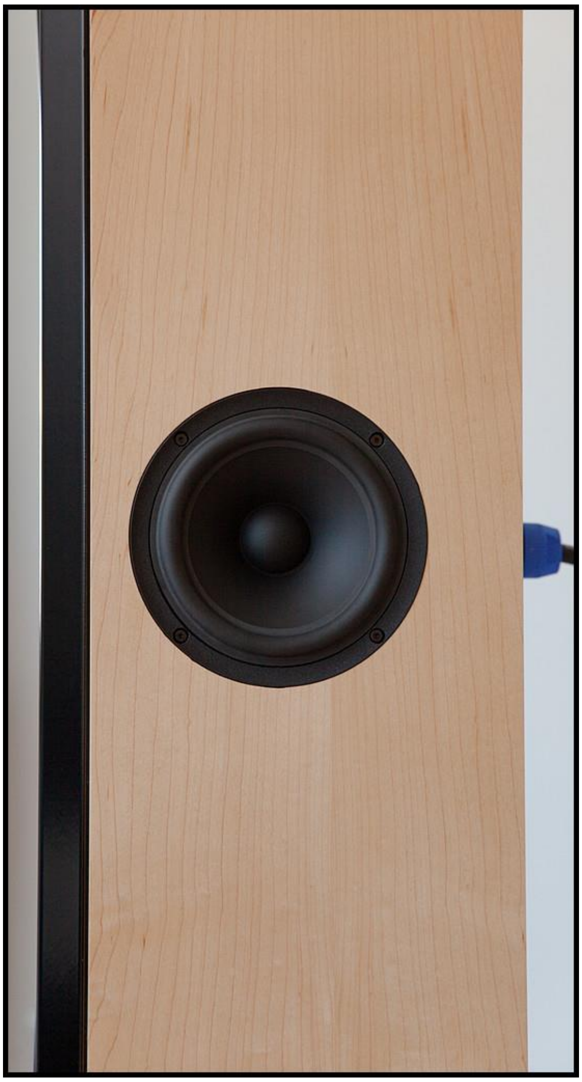
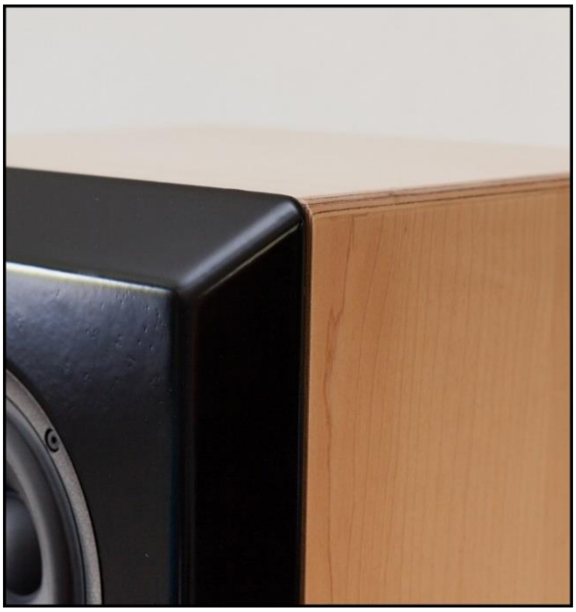


Figure 25: Sphere-based directivity index

More Pictures





Specifications

Free Field frequency range:	100 Hz – 18 kHz, ± 1.5 dB
Horizontal beam angle:	120° @ 600 Hz – 10 kHz
Vertical beam angle:	35° @ 1 – 8 kHz
Distortion factor:	< 0.3% (200 Hz – 10 kHz) in 1 m, 100 dB SPL
Woofer:	4 x 170 mm cone
Midrange:	8 x 50 mm dome
Tweeter:	1 x 145 mm AMT
Crossover frequencies:	100 Hz (24 dB/oct)
	600 Hz (Horbach-Keele)
	2400 Hz (24 dB/oct)
Amplifiers:	4 x 125 W RMS @ 4 Ω
Dimensions:	1000 x 310 x 280 mm (H x W x D)

References

1. Ulrich Horbach and D.B. Keele, Application of Linear-Phase Digital Crossover Filters to Pair-Wise Symmetric Multi-Way Loudspeakers Part 1, Part 2
2. J.G. Tylka, *On the Calculation of Full and Partial Directivity Indices*