Audibility of tweeter performance beyond spectrum and phase

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Introduction

In consumer advertising as well as in professional reviews, the quality of loudspeakers is often claimed to emanate from the physics of the actuator. Particularly the driver principle of the tweeter unit would thus account for complex perceptual attributes of sound quality:

> *"Its design principle gives the [...] an exceptionally fast speed of response that reinforces the impression of musical lightness and effortlessness. A conventional diaphragm would be unable to provide a comparable degree of direct and spirited liveliness. "*[1]

Moreover, criteria related to spatial impression such as for instance a 'three-dimensional' reproduction of acoustic stage and a precise localization of sound sources are claimed uniquely for certain tweeters. The aim of this study is to assess objectively whether auditive differences between different high frequency drivers can still be found, once differences due to frequency and phase response irregularities, enclosure effects, and room interaction have been eliminated. For this purpose, stereo sets of 2-way loudspeakers, equipped with different high frequency drivers, were equalized in an anechoic environment using FIR filtering. Blind-comparison listening tests were performed using dynamic binaural loudspeaker simulations, in order to find out, whether the current state of FIR equalization would be able to reduce differences due to different high frequency driving principles down to an inaudible residue.

Previous studies

Binaural recording and reproduction has been shown to be a convenient way to provide a direct A/B comparison of sound reproduction systems [2], thereby avoiding typical problems such as position/room-interaction and human short time memory for timbre. In [3] the capabilities of FIR filters to equalize loudspeakers for linear on-axis amplitude and phase response were assessed. Although the frequency response could be fairly well linearized, listening tests with static dummy head recordings revealed, that some differences were still audible (75% detection rate). It should, however, be considered that, in order to effectively show FIR filters capabilities in [3], very different loudspeakers (2- and 3-way) were compared. Hence, speaker designs using woofers ranging from 6" to 12" completed by 1" to 2" dome or even horn-loaded tweeters were assessed. There was no perfect vertical alignment of the acoustical centers, and only a semi-anechoic acoustic environment was used. Thus, differences due to directivity as well as to different enclosure and baffle sizes could not be eliminated. Still, it was suspected that audible differences could be due to enclosure effects and to different wave front curvatures emitted by the drivers inducing specific reflections at the dummy head and different eardrum signals. This assumption was examined in more detail in [4]. Here, binaural impulse responses (BIRs) of 2-way monitor boxes and one larger PA loudspeaker were collected at a distance of 2.2 m at the sweet spot of a recording studio mock-up (desk, seat, side rack) placed in the same semi-anechoic space. From listener reports and from inspection of post-processed static binaural recordings, it was concluded that binaural recordings allow distinguishing (vertical) spatial distribution of the loudspeakers' individual transducers, which was not possible with monaural measurements.

Method

For our study six different high frequency drivers where flush-mounted together with a 6'' woofer in a quasi-infinite baffle (w: 1 m, h: 2 m). In order to minimize interactions with the environment and influences of speaker directivity, all measurements were taken in a large anechoic chamber with a cut-off frequency of 63 Hz. Tweeters comprised different drive types and membrane materials: an air motion transformer, a ribbon tweeter, an aluminum calotte, a silk calotte, a ring radiator, and a magnetostatic tweeter were used (diameters from 2.5 to 11 cm). All drivers were chosen to be combinable at 2 kHz crossover frequency with the woofer. Frequency responses were measured on the tweeter axis at a distance of 2.7 m. Tweeters could be replaced in the baffle, while ensuring that their centers were always situated at the same location in the baffle. Using a commercially available FIR loudspeaker processor it was possible to equalize the tweeter-woofer combinations to exhibit a flat (< ±1 dB) on-axis amplitude response as well as a linear phase response between 155 Hz and 21 kHz. Figure 1 shows amplitude responses of the six unequalized tweeters as well as those of the equalized tweeter/woofer combinations. Binaural impulse responses (BIRs) where acquired for each tweeter/woofer combination using the FABIAN measurement robot [5]. Its dummy head – equipped with measurement microphones at the blocked meatus entrance – can automatically be rotated above the torso. FABIAN was positioned with the center of the dummy head at the same position as the measurement microphone. To be able to simulate a stereo setup in the listening test, the HATS' frontal orientation relative to the baffle had to be adapted before the measurement of every tweeter/woofer combination. Thus, FABIAN was rotated around its vertical axis to aim at +30° resp. -30° on-axis, according to a central listener position between a left and a right speaker in a 2.7 m stereo triangle.

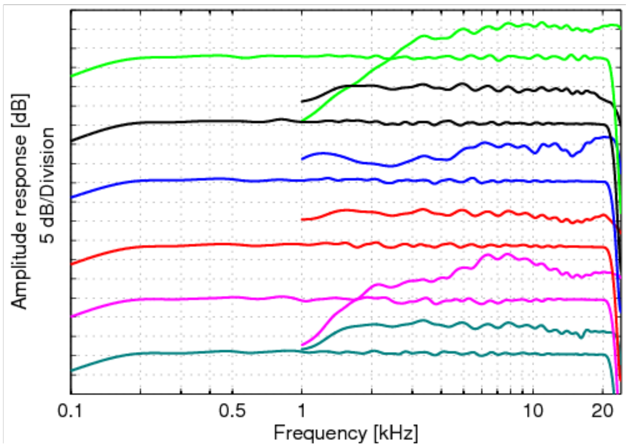

Figure 1: Pairs of the same color show unequalized tweeters (above) and equalized full range responses (below). Different colors represent tweeters with different drive types.

For both torso orientations, BIRs were measured within a range of horizontal head movements of ±80° in 1° steps. From visual analysis of the binaural difference spectra when plotted above the horizontal angle of head movements, only minor differences in the wave fields of the six equalized tweeter/woofer combinations could be found. In Figure 2 differences between the most unequal pair of speakers – the ring radiator and the magnetostatic tweeter – are shown. As the right ear reaches the contralateral position, stronger deviations arise in the high frequency range.

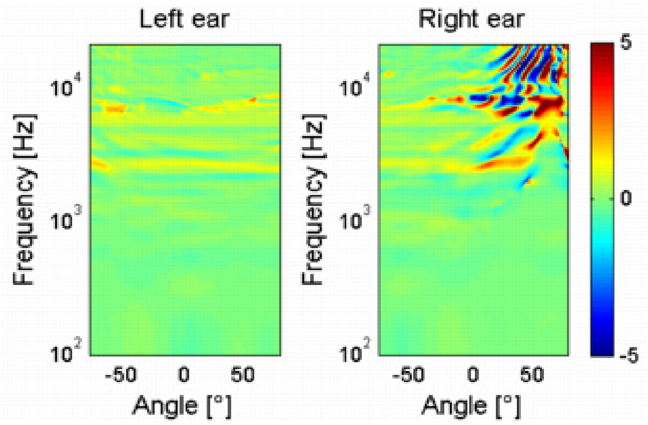

Figure 2: 1/6 octave smoothed spectral differences in BRIRs over head orientation (most different pair of tweeters,’ left speaker’*)*

As known from contralateral HRTFs narrow notches dominate the high frequency range, which, in case of small sound field differences lead to exaggerated differences. However, due to the interaural level difference, one has to consider an absolute level difference of ca. 10–20 dB between left and right plot. The ipsilateral ear, dominating the subjective impression of sound coloration, never shows differences of more than ±1.5 dB. At 8 kHz, slightly mistuned pinna notches produce some differences.

The listening test was performed using dynamic binaural synthesis. Virtual stereo loudspeaker setups were auralized by convolving binaural impulse responses in real time with audio material, while dynamically exchanging BRIRs according to the tracked head position of the listener. Due to the marginal differences in the BIRs, the speaker pair with the largest differences was selected for a first evaluation in the listening test. In order to reveal small differences, a sensitive ABX test design was chosen, where subjects could instantly compare the different virtual loudspeaker setups. In order to test an effect size of 75% detection rate at a 5% significance level while maintaining a test power of 95%, 40 repetitions per subject were necessary [6]. Ten different audio stimuli were chosen covering a wide variety of musical material such as pop/rock, jazz, world and classical music, a male and a female speaker, and pink noise. To reach the total number of 40 trials per subject, each stimulus was presented four times within a random sequence via spectrally compensated STAX headphones.

Results

Ten subjects performed the listening test, nine of them showed no significant result (overall detection rate: 47.4 %). One subject with a significant detection rate of 70% – while stating that it actually heard no difference – could not repeat its result in a re-test on a later day. Thereby, one has to consider that due to the significance level of 5%, a blind alarm *has* to occur on average at every 20th test, even if subjects are only guessing.

Conclusion

When eliminating frequency and phase response irregularities, baffle and room interaction, non-linear behavior, and distance effects, a blind-comparison listening test could not reveal audible differences between different types of tweeters. Neither the material nor the actuator principle, neither the tweeters geometry nor the specific form of wave fronts in the far field could be shown to be distinctive features of different tweeter types. Divergent results of previous studies can only be explained by aforementioned shortcomings of the test designs. Furthermore, when excluding room and baffle interaction, FIR equalization seems to be capable to compensate for the behavior of different loudspeakers at the sweet spot within a typical range of horizontal head movements.

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