A Method of Directivity Pattern Control in Multi-way Loudspeakers through a pairwise geometric Arrangement

Abstract

Due to increasing availability of low-cost active electronics, different aspects of the design of loudspeakers such as the use of different filter characteristics and frequency response linearization methods are easier to handle. This thesis presents a method to control the horizontal and vertical directivity pattern of a multi-way speaker. It is based on the fundamental idea of a symmetrical arrangement of multiple woofers surrounding a centered tweeter. As an introduction, findings from previous work are summarized to derive and analyze concepts, which are important for proper function of the considered alignment. To investigate the effects of various parameter changes two test speakers are designed to examine their directivity patterns through measurement. The presented arrangements show a balanced behavior within the measured polar response diagrams and sonograms, which behave very similar horizontally and vertically, wherefore sound level differences caused by poor listening positions are small compared to known concepts.

Introduction and previous Work

The following paper is based on an arrangement published by Joseph D'Appolito in 1983 which is characterized by a center tweeter with a midrange driver above and below it. These two operate in phase und radiate the same frequency range. Thereby it is possible to eliminate asymmetries in the vertical directivity pattern, which occur in ordinary tweeter-midrange configurations. A tilt in the vertical radiance axis normally results from either a depth difference of the acoustic center between tweeter and midrange driver or the usage of electric filters which cause such a behavior. To create a directivity pattern that is as wide as possible the utilization of Butterworth filters third order is necessary and the distance between the acoustic centers of the two midrange drivers should not be larger than two-thirds of the wavelength at the crossover frequency [1]. In 1996 Mithat Konar examined the interaction between the two midrange drivers which cause frequency response nulls due to destructive interference. Because of the time displacement at different angles, the output of the midrange chassis will meet at a point where they radiate out of phase whereby the overall output becomes zero. This effect depends on the distance between the drivers, the angle and the distance to the listener [2].

New Concept

To attenuate the impact of this interaction and to create a vertically and horizontally symmetric directivity pattern an arrangement is tested, which consists of several midrange chassis arranged around a centered tweeter. To assess different aspects in the design two test loudspeakers are built with one containing four midrange drivers and the other one containing six.

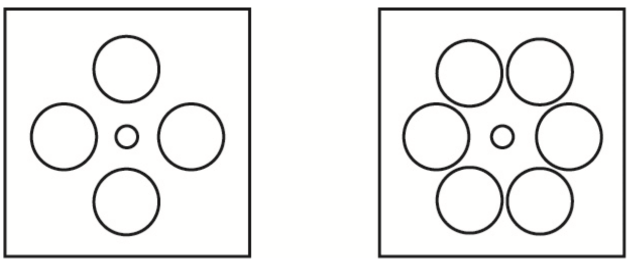

Fig. 1: Schematic illustration of the tested speaker designs.

The main difference between the tested alignments is the distance between the midrange drivers. Six of them cannot be positioned as close as four in the smaller version, thus, exceeding the limitations of the driver distance given by the D'Appolito arrangement. In addition, new interactions between the adjacent drivers appear which might neutralize the effect of cancellation between opposing midrange speakers. Furthermore, the behavior at angles between 0° and 90° around the tweeter axis needs to be evaluated to show improvements on a standard D'Appolito approach, a tweeter-midrange design or a coaxial speaker.

Arrangement in Detail

To follow the distance restriction a tweeter with a small ground plane is required which provides a low crossover frequency at the same time. The utilized tweeter can be used down to 2000 Hz with a ground plane having 52 mm in diameter. Calculations have shown that practicable midrange speakers should be around 6 to 8 cm in diameter to provide enough volume-level at lower frequencies while their acoustical centers are still close enough. In this attempt, 8 cm midrange units are used which are still operating as spherical radiators at the crossover frequency of 2000 Hz. The two enclosures have the following sizes and distances between the woofers:

4 woofers	
dimensions [width * height * depth]	25,5 * 25,5 * 22 cm
tweetercenter to woofercenter	6,6 cm
woofercenter to woofercenter (diagonal)	13,2 cm
woofercenter to woofercenter (side by side)	9,3 cm
6 woofers	
dimensions [width * height * depth]	32 * 32 * 22 cm
tweetercenter to woofercenter	9,5 cm
woofercenter to woofercenter (diagonal)	19 cm
woofercenter to woofercenter (side by side)	9,5 cm
woofercenter to woofercenter (over the next)	16,5 cm

Tab. 1: Enclosures sizes and woofer distances.

Measurements

The used measurement hardware was calibrated to eliminate falsification through the microphone or the sound card. The distance was 20 cm and the measurements were sampled to reduce room influence. Early attempts showed that the usage of Butterworth filters third order displays best results in the width-behavior of the directivity patterns. The comparison of the vertical directivity pattern between a normal D'Appolito arrangement and the test enclosure with 4 woofers shows that the radiation pattern of the test enclosure is at least slightly better than the standard configuration. Both were measured at 1600 Hz and 2000 Hz at different angles. At an angle of 0° the D'Appolito arrangement is positioned vertically and the test-enclosure is positioned as a cross. At 45° the test-enclosure is rotated around the tweeter axis and corresponds to an X.

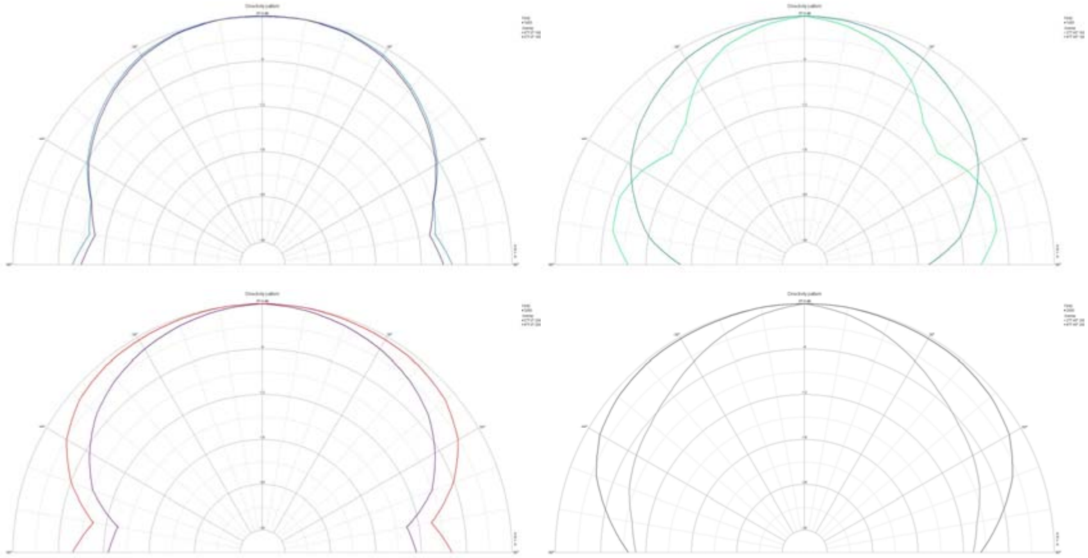

Fig. 2: Directivity patterns of two woofers versus four woofers. Top left: 1600 Hz, 0°. Top right: 1600 Hz 45°. Bottom left: 2000 Hz, 0°. Bottom right: 2000 Hz, 45°.

The difference at 1600 Hz and 0° is small, but it grows when both arrangements are rotated. The test enclosure shows a better performance at the crossover frequency of 2000 Hz, which gets more obvious at bigger angles. A similar result can be experienced with the comparison of the four woofer enclosure with the six woofer enclosure. For the bigger test enclosure an angle of 0° means that two woofers are left and right next to the tweeter and an angle of 30° means that two woofers are above and beneath the tweeter while two gaps are next to it.

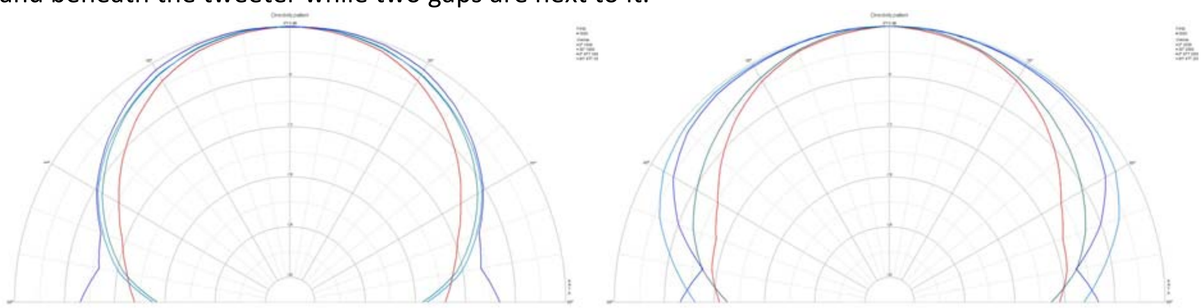

Fig. 3: Directivity patterns of both arrangements. Four woofers versus six woofers. Left: 1600 Hz. Right: 2000 Hz.

It can be seen that the higher woofer distance causes a thinner directivity axis. At 1600 Hz the 30° arrangement of the bigger test-box is close to the cross and X arrangement of the smaller version but the difference grows significantly at 2000 Hz. The illustration as sonograms increases the impression of the smaller test enclosure having a wider directivity pattern. Also, the polar axis tilt of a normal tweeter-woofer configuration can be shown.

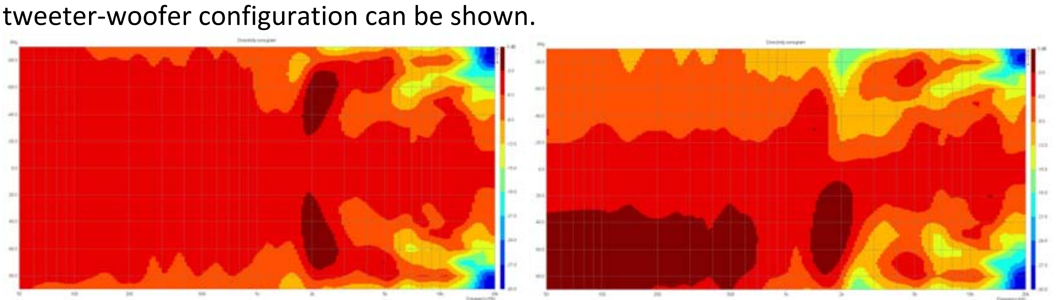

Fig. 4: Sonograms for tweeter-woofer arrangement. Left: horizontally. Right: vertically.

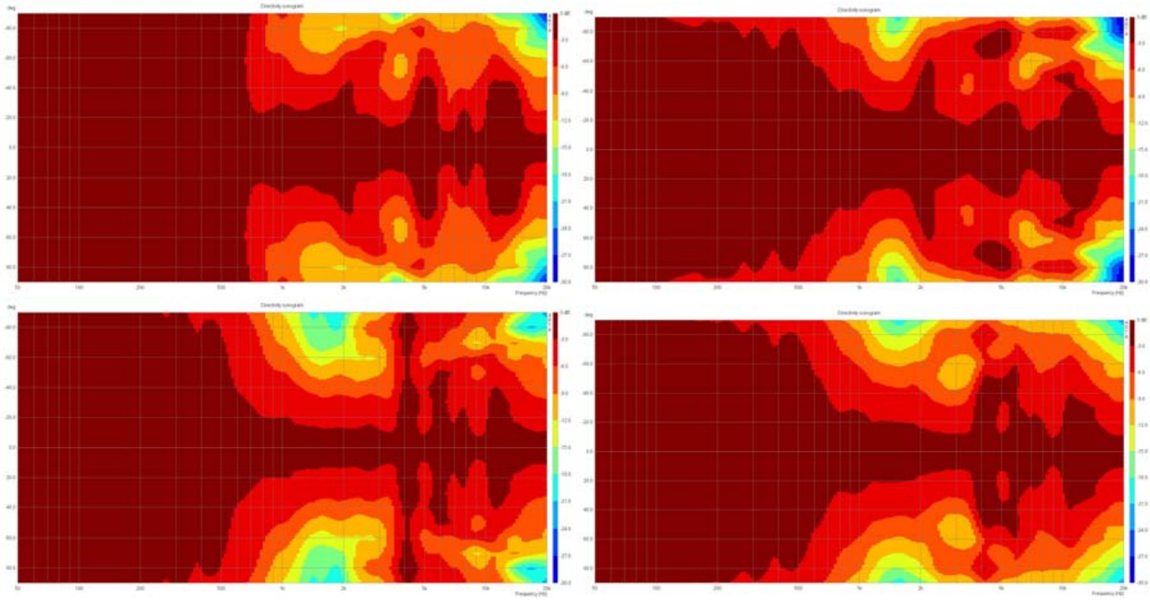

Fig. 5: Sonograms. Top left: four woofers 0°. Top right: four woofers 45°. Bottom left: six woofers 0°. Bottom right: six woofers 30°.

Conclusion

The comparison between the different attempts to produce a directivity pattern that is as wide as possible and without polar axis tilts has shown a variety of restrictions. The most important one is the distance between the woofers wherefore the bigger test box showed a thinner directivity pattern. The more woofers are used, the smaller their diameter needs to be. 8 cm seem to be too much for this construction. The fundamental idea concerning the creation of a directivity pattern that shows little variation to a change in listening angle was successful. No side radiation axes occur at angles between the cross or X arrangement. However, the change in magnitude at different angles is smaller the more woofers are used. This leads to the desire of having as many woofers as possible without an increase in driver distance. A number of 8 woofers seems to be the restriction when practicable crossover frequencies are desired. Compared to a coaxial speaker this arrangement benefits from the freedom to use a high range of different midrange drivers and will suffer from less intermodulation distortion because of a different radiation axes [3]. Furthermore the heat dissipation will be increased because the total output is divided into four or more voice coils. This concept needs further investigation concerning the amount of intermodulation distortion and the impact of more and smaller midrange chassis. In addition the usage of a waveguide for the tweeter could be tested because of the immunity of the D'Appolito arrangement towards depth offset.

References

[1] D'Appolito, Joseph (1983): A geometric Approach to eliminating lobing Error in Multiway Loudspeakers, presented at the Audio Engineering Society Convention 1983

[2] Konar, Mithat (1996): Vertically Symmetric Two-way Loudspeaker Arrays Reconsidered, presented at the Audio Engineering Society Convention 1996

[3] Klipsch, P. W. (1976): A Note on Modulation Distortion: Coaxial and Spaced Tweeter-Woofer Loudspeaker Systems, J. Audio. Eng. Soc., Vol. 24, 1976