

2.3 Horn optimisation

In the first step the horn should be designed to achieve the desired directivity ($60^\circ \times 40^\circ$). To be as close as possible to the final configuration, the dimension of the baffle and position of the horn should be considered. In this particular case of a rotatable horn, it is sufficient to use only the width of the baffle during optimisation. Accordingly, the task is to find a horn geometry which can be mounted using a quadratic flange not exceeding 220 mm. The assumed cabinet width for the simulation model is 250 mm. The horn's length is not defined and will result from the simulation. To save computational time, only a quarter section of the model is processed, using the fact that the geometry has two planes of symmetry.

Figure 4 shows the procedure for optimising the horn with respect to a desired directivity or other properties like throat impedance or efficiency. The optimisation begins with an initial set of parameters to define the geometry to start with, boundary conditions and settings for the mesh generation and post-processing. From the geometry parameters, the edges of the geometry are generated and from the set of edges the simulation mesh is computed. After solving and post-processing, a set of results is calculated, like horizontal and vertical directivity pattern, throat impedance or estimates for distortion caused by the horn. Based on the results, the parameters of the geometry are modified and the next iteration is started. With some experience in horn design it is possible to reach the desired result after 10 - 50 iterations. Computation time using a PC with quad-core 2.6GHz CPU is about 1-2 s for each frequency for a mesh with 1000 nodes. During the first iterations, the basic behaviour of the horn can be optimised by processing only few frequencies. A cycle of iteration needs about 1 minute for a middle-sized horn with two planes of symmetry. With ongoing optimisation more detailed results require more frequencies to be processed and probably a refined mesh with more elements to get smoother results at high frequencies. Computation time can be 30 minutes or more, then, for one iteration cycle, but this can easily be reduced by increasing the number of CPUs involved.

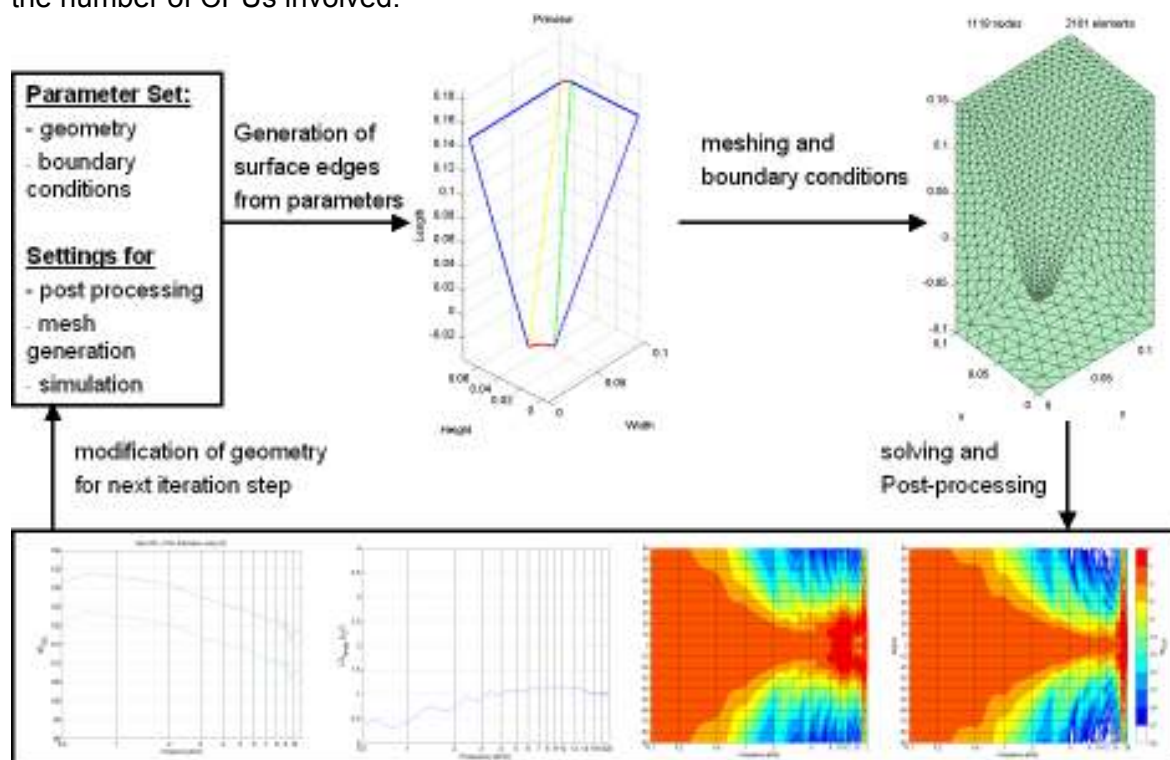


Figure 4 Horn optimisation using BEM and post-processing.

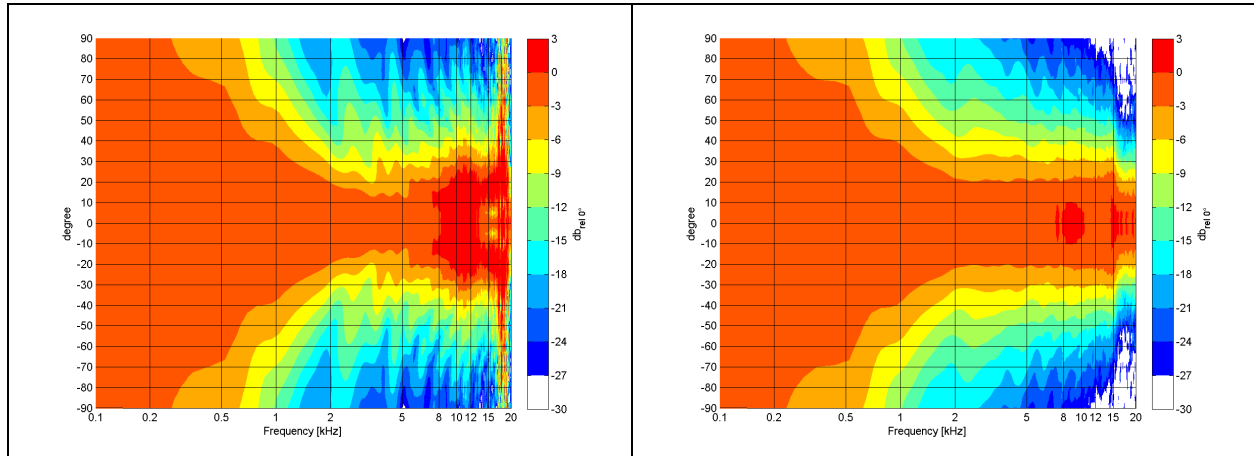


Figure 5 Horizontal directivity after the first iteration step (left) and after 14 iterations (right)

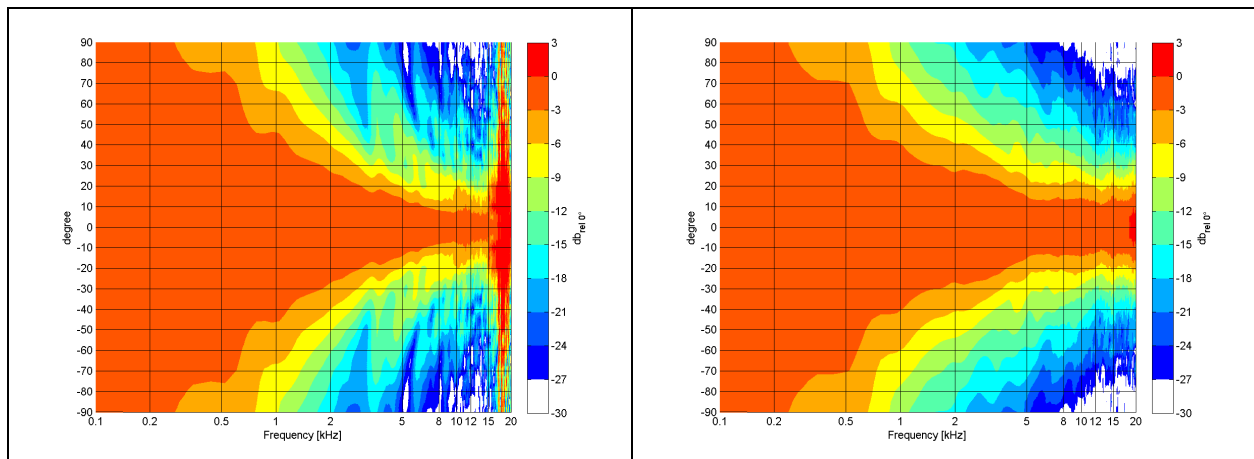


Figure 6 Vertical directivity after the first iteration step (left) and after 14 iterations (right)

Figure 5 shows the horizontal directivity of the $60^\circ \times 40^\circ$ horn at the beginning of horn optimization and after 14 iterations. Starting from 2 kHz, the horizontal dispersion shows a nearly perfect behaviour of 60° -6dB-beamwidth up to 15 kHz. Off-axis sound pressure decreases very smoothly and no peaks or dips are visible. Figure 6 shows the results for the vertical direction. One can clearly see that the 40° -beamwidth can not be reached over the complete frequency range using a conventional horn of this size. Anyhow, optimisation is stopped at this point and the next step, studying the interaction of woofer, horn and x-over, is to be done.

2.4 Loudspeaker system design

To study the complete system, the 8"-woofer and optimised 1"-horn have to be combined in a CAD-model. Figure 7 shows the CAD of the test-setup corresponding to Figure 3. It has to be noted that some space between horn and woofer is left which will be occupied by the horn flange and the chassis of the woofer in the "real life model". Now, a surface mesh is created and the radiation is calculated separately for all membranes. Accordingly, for this two-way cabinet, one set of results for the woofer membrane and one set of results for the 1"-horn is

obtained. Computation time for this mesh with about 3500 nodes is 50 s for each frequency using a quad-core 2.6GHz CPU. To get a general idea of the speaker behaviour, the simulation can be started with 1/3 octave frequency stepping which needs about 15 minutes in this case.

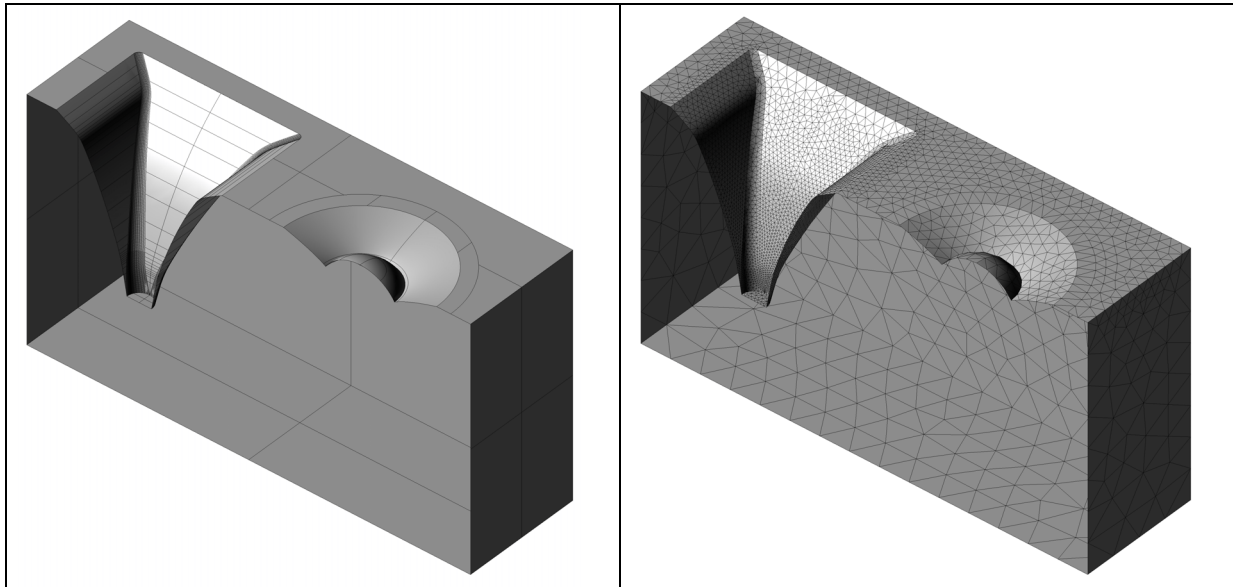


Figure 7 CAD-Model of the 8" woofer cabinet with optimised 60°x40° 1"-horn (left) and surface mesh (right). The mesh has about 3500 nodes.

Directivity, loading impedances and also coupling impedances between the various membranes can be obtained by linear post-processing of the BEM. At this point of the development it is also possible to couple lumped element models or two-port models to the loading impedance and, thus, the sensitivity and the power limited maximum SPL for each way could be calculated very accurately [5]. The directivity of the system is obtained by multiplying the inverted frequency responses of each channel with x-over functions and superimposing the results. This procedure corresponds to using inverting FIR-filters [4] to create the EQing for the single ways of the system.

Figure 8 shows directivity and directivity index when using two different x-over functions, a Linkwitz-Riley-filter of 2. order with cut-off at 1500 Hz and a Linkwitz-Riley-filter of 8. order with cut-off at 1000 Hz. The second order set-up is a typical configuration when using passive networks or in order to increase the directivity index in the x-over region between 1 kHz and 2 kHz. In contrast, the 8. order setup would be used to get a wider coverage in the vertical direction. Now, other settings can be tested and studied to achieve a good compromise between vertical coverage and directivity index.

At this stage of loudspeaker development, one can clearly evaluate if a desired directivity can be achieved or not and which kind of x-over and cut-off frequency will be necessary. Accordingly, if a concept does not reach the directivity requirements, this would be the right stage to discard everything or to make conceptual changes. The crucial point is, that no prototype is necessary to test the basic concept and also no time consuming measurements have to be made. This is even more significant if more complex and larger systems are to be developed, as costs for prototyping can be quite high in this case.

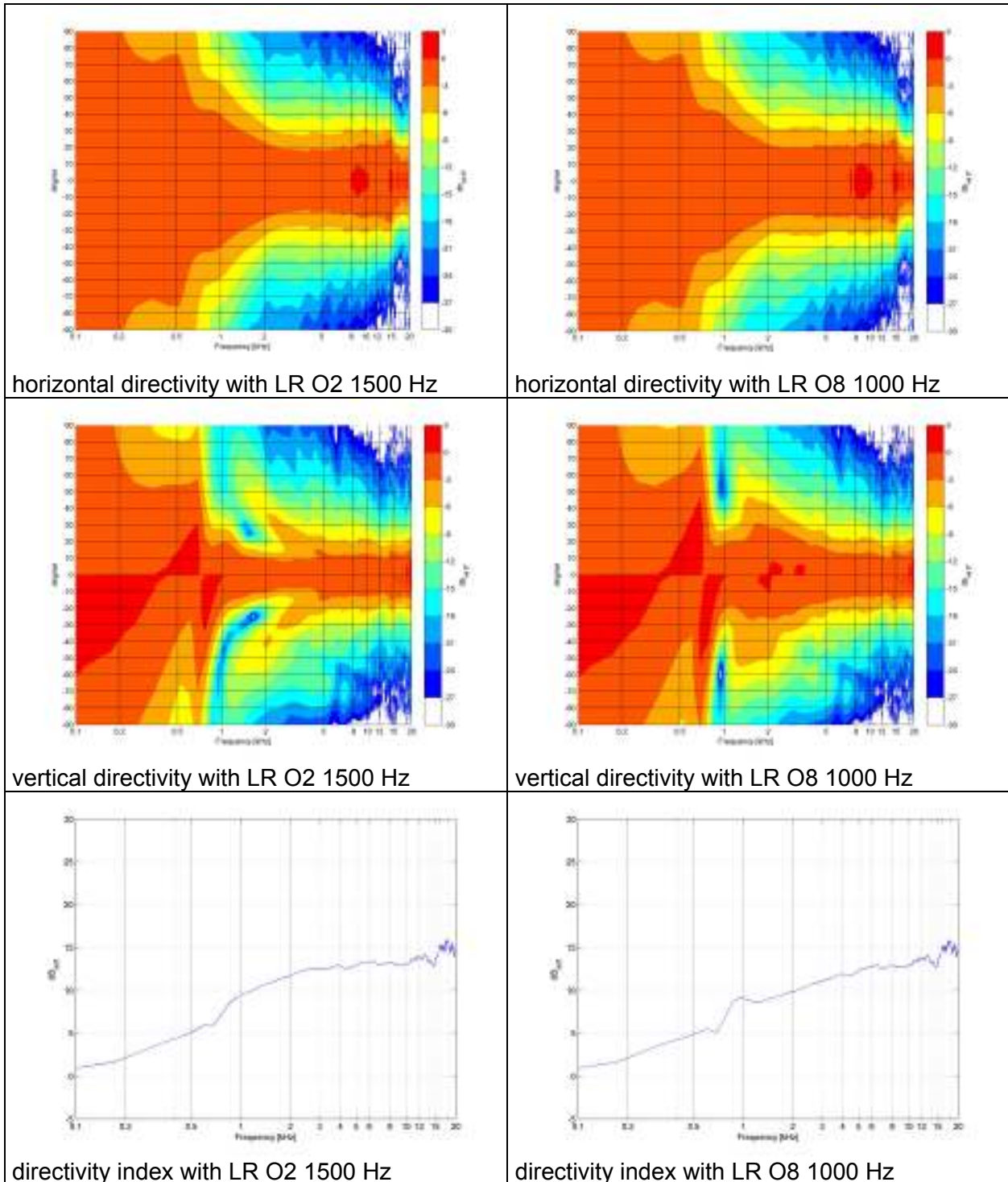


Figure 8 Directivity results for two filter settings: left column is calculated for a Linkwitz-Riley-filter of order 2 and x-over at 1500 Hz, right column is the result for a Linkwitz-Riley-filter of order 8 with cut-off at 1000 Hz.

3 Conclusions and Outlook

Numerical simulations are an indispensable tool for directivity engineering of public address loudspeakers. Optimisation of components, as waveguides, horns, diffusers and the simulation of different loudspeaker concepts including cabinet and x-over design can be done with high accuracy without building a prototype for each iteration during loudspeaker development. With increasing computational power of desktop PCs and affordable PC memory, the use of numerical methods for loudspeaker design will become more and more attractive in future.

Another very powerful application is to use post-processing results of a simulation model, like shown in Figure 7, together with electro-acoustic simulations for designing complete sound systems in large venues. This would allow to test loudspeaker models even if they only exist as rough concept in realistic venues under consideration of their interaction with room-acoustics. The investigation and verification of such extensive simulations will be an interesting task in future.

References

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