OLE WOLFF

Acoustic design of True Wireless earphones (TWS) using COMSOL Multiphysics

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Scope

In-ear headphones are complex technology packed in a very small space. With the evolution into true wireless headphones this is even more the case, since a lot of technology is expected by the users e.g., Bluetooth, active noise cancelling, head set functionality, touch interface and long battery life. This has made the task of designing a well performing and compact headset even more challenging.

This whitepaper shows how Ole Wolff application engineers can utilize COMSOL Multiphysics in making acoustic simulations of the performance of a product. This can be done early in the development process to test concepts without the need of physical prototypes, which can be difficult to produce accurately due to the small size of the products and details.

In this paper, the anatomy of a TWS device is described and it is shown how a functional simulation model can be made. A case study model is then used to show how changes in geometry and acoustic meshes in the system can change the performance of the system. The case study uses a custom Ole Wolff TWS design, since we cannot share geometries of the real products that use Ole Wolff drivers. The design is not finished in any way and may not be producible, but it served to show how development work can be done using acoustic performance simulations. The case study TWS design is shown in *Fig. 1*.

Fig. 1

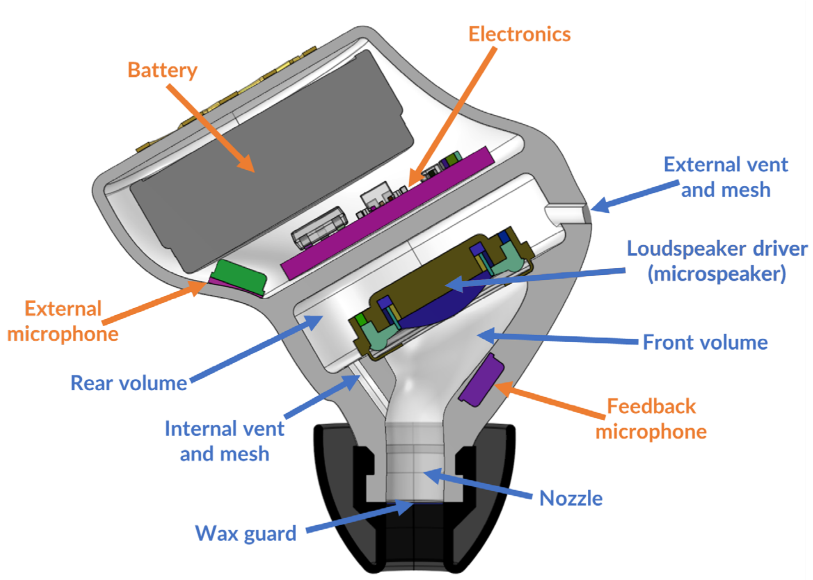
Custom Ole Wolff TWS design used as case study.
(Not ready for production, only for educational use).

Elements in a True Wireless earphone

In *Fig. 2* the anatomy of the case study TWS earphone is seen. In a compact device like this a lot of technology is packed into a very small space. The system uses an OWR-1030T-16F driver, measuring 10mm (diameter) x 3mm. Smaller drivers are available in the Ole Wolff catalogue as well as special purpose drivers, like drivers that have a built-in microphone for ANC (Active noise cancellation).

Often, the loudspeaker driver, which is the primary functional component in headphones, is smaller than the battery of the device.

Fig. 2



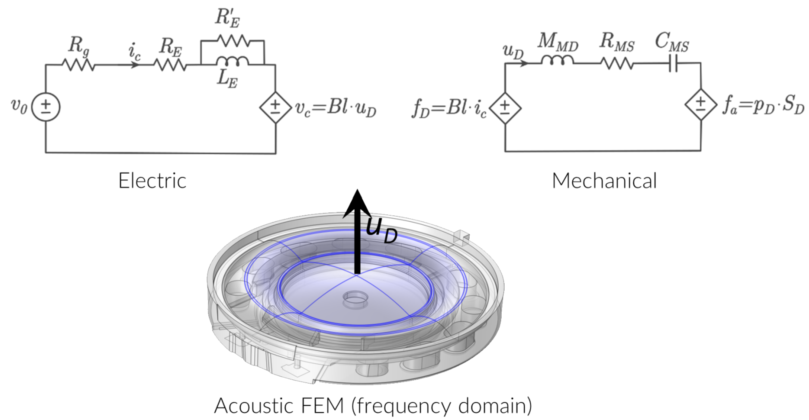
Anatomy of a TWS earphone. Blue text and arrows mark elements relevant to the acoustic performance.

Building a functional simulation model

To effectively simulate the performance of the earphone, a simulation model is built in the COMSOL multiphysics simulation software. The detailed electro-mechanical behavior of the loudspeaker driver is modelled using a lumped parameter equivalent circuit, that is then coupled to an acoustic finite element model, which models the acoustic behavior of the device geometry.

Fig. 3 shows an overview of the elements in the lumped circuit and how it is connected to the acoustic FEM model.
Below the nozzle in the geometry a boundary condition representing a 711 coupler is applied. This impedance replicates the measurement setup often used for earphone measurements.

Fig. 3

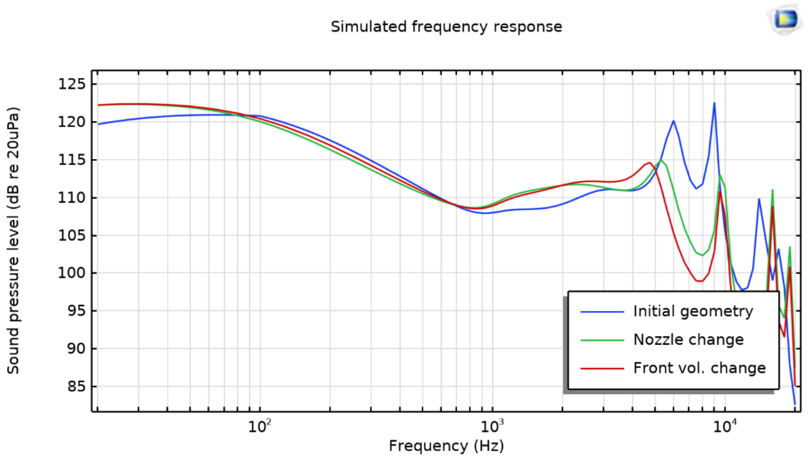


Simulation model overview. Electric and mechanical functionality is modelled using lumped parameter circuit, which is bidirectionally, coupled to an acoustic finite element model. This coupling captures both forward effects (electrical to acoustic) and reverse effects (acoustic loading effects).

Simulation results and insights

After building a functional simulations model it can be treated as a virtual prototype. Here geometric ideas can be tested without the waiting time and technical complexity in producing physical samples.
For the case study model described in this paper, the simulation time for a frequency response from 20 Hz to 20 kHz in 1/3-octave steps is less than 15 min, once the model has been set up. So significantly shorter than making physical samples and measuring them.
Simulation results of an initial geometry as well as a system with some geometry changes are seen in *Fig. 4*.

Fig. 4



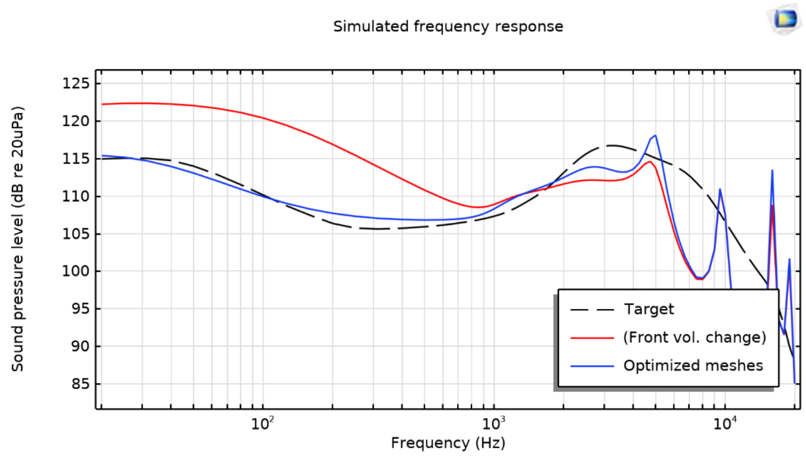
Simulated frequency response of TWS system show the effect of geometric changes.

From the simulation results, it is clear that geometry changes have a big effect on the frequency response.

Another parameter to change to get the desired frequency response is the meshes in the system. This case study system has four meshes: on the back of the driver, a wax guard, one on the internal vent and one on the external vent. These can be adjusted by hand and the effect revealed by running the simulation model again, but here another advantage of simulation models can also be utilized; running an optimization routine.

To use automatic optimization on the system, all meshes has been parameterized. By introducing a target curve, the model can be set to change the meshes automatically to get a frequency response as close to the target curve as possible. The outcome of such an optimization is shown in *Fig. 5*.

Fig. 5

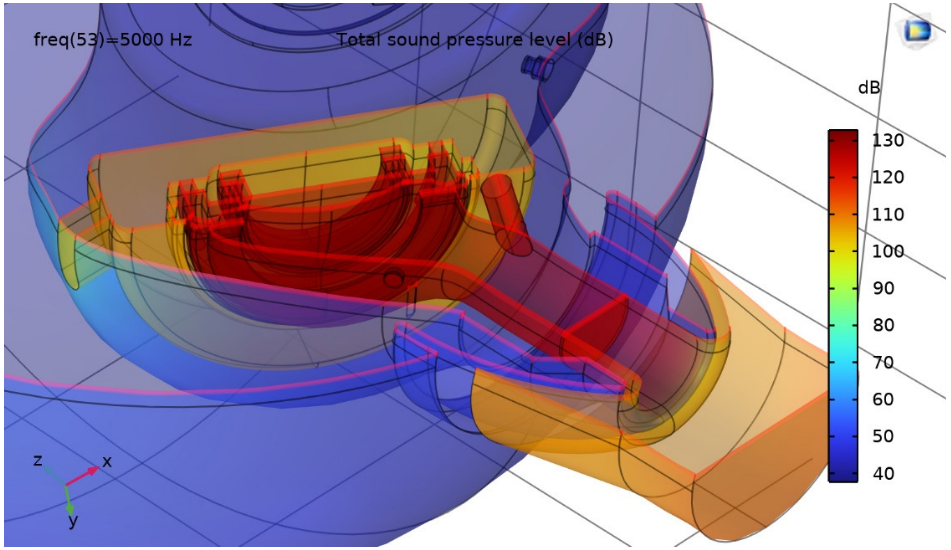


The blue curve shows the response of the same geometry as the red curve, but with meshes automatically optimized.

While the response does not perfectly match the target response curve, it is evident that it is much closer than the initial solution. Further geometric modification, along with the mesh optimization routine, would make the match even better, but this is not done here since it is only a case study.

To investigate what to change in the geometry, the simulation model can be used to look inside the system to show e.g., why peaks in the frequency response occur. An example of this is seen in *Fig. 6*, where the sound pressure level inside the geometry is shown. This insight would not be possible to directly produce in a physical measurement, where all interpretation of the frequency response would rely on intuition and assumptions about what cause peaks and dips in the frequency response.

Fig. 6



Sound pressure level inside the TWS at 5kHz where there is a peak in the frequency response.

Conclusion

This white paper has shown how a simulation model can be used to evaluate the performance of a TWS without building any physical prototypes. It has also been shown that the effect of geometric changes can quickly be investigated and how automatic optimization can be used to optimize parameters, such as the meshes in the system, to push the performance closer to a predefined target performance. All this done virtually with no waiting time of cost of producing physical samples. Other aspect of acoustic systems can also be simulated, such as the feedback to the microphones in the system. This has not been shown in this paper, but simulation models open many possibilities like that.

Simulation software is costly and so is maintaining the skill to perform advanced system simulations. For many companies it is not feasible to have a dedicated acoustic simulation expert in house. That is one of the reasons collaborating with Ole Wolff will benefit your projects; we offer fast and specialized simulation support on your products at no extra cost, when you use our loudspeaker- or headphone drivers. The support is free for OW customers with no need to maintain simulation software licenses and keep the skills in house.

Contact your local sales representative for more information about collaborating with Ole Wolff on your next audio product.