Hi-Fi Hearing Aids with Multiphysics Modeling

The need for hearing aids is growing, and manufacturers are coming up with new technologies to make these devices more attractive and effective. COMSOL® proved very useful due to its ability to easily handle arbitrary equations and provide another dimension to our integrated signal processing model.

BY MADS J. HERRING JENSEN, WIDEX A/S

With the Baby Boomer generation now reaching retirement age, it should be no surprise that the number of people who suffer from hearing loss is increasing. The American Academy of Audiology estimates the number of Americans in that situation at 36 million. It also adds that more than half of the people with hearing loss are younger than 65, with approximately 12% of all children aged 6 to 19 have noise-induced hearing loss. Many of these people are candidates for hearing aids.

Meeting the demands of these markets, hearing aids are becoming more effective and less obtrusive. With a BTE (behind the ear) model, a tube connects the electronics-based module to an ear mold located within the ear channel. Some small amount of amplified sound inevitably leaks out from around the ear mold, and if the hearing aid is not properly designed, this sound can be picked up by its microphone and lead to squawks and other feedback effects. In addition, sound radiating through the tubing can also lead to feedback. To eliminate these effects, designers are looking for improved materials for the tube, optimal placement of the microphones as well as feedback algorithms that reduce the gain at critical frequencies.

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Figure 1: A BTE (behind the ear) hearing aid transfers sound through a plastic tube to an ear mold that fits into the hearing channel. Note the two microphone inlets on each unit (arrows).

Working Towards Better Hearing

A privately-owned company and with a world market share of approximately 10%, Widex has always devoted considerable resources to R&D. Now more than 50 years old, Widex has roughly 1,850 employees around the world. In 1997 we launched the world's first fully digital CIC (completely in the canal) hearing aid; in 2006, our Inteo was the first hearing-aid line with integrated signal processing.

Modeling has made a major contribution in the stability and robustness of our feedback algorithms because of the greater insight we get from modeling with COMSOL. Previously, the feedback algorithm was based on experimental measurements made in test setups using the hearing aid's two microphones. However, many aspects must be considered to determine the optimal algorithm — including the shape of the pinna (the projecting outer portion of the ear, also known as the auricle) and the location of the hearing aid on the ear. We can add details that are extremely difficult to acquire experimentally, including radiation from the earmold and earmold tube and internal structural vibrations. And while today all models in a given product line use roughly the same feedback algorithm, in the future it might be possible to scan an individual's ear area and use mathematical modeling to design an individualized feedback algorithm.

Modeling Thermoviscous Acoustics Behavior

We found COMSOL Multiphysics® to be particularly useful in our studies, which are based primarily on thermoviscous acoustics, because the underlying equations are not standard in any commercial simulation package we are aware of. Thus, COMSOL's ability to let us incorporate our own systems of equations was vital for the development of our hearing-aid models. In addition, the freedom to specify arbitrary boundary conditions was very useful.

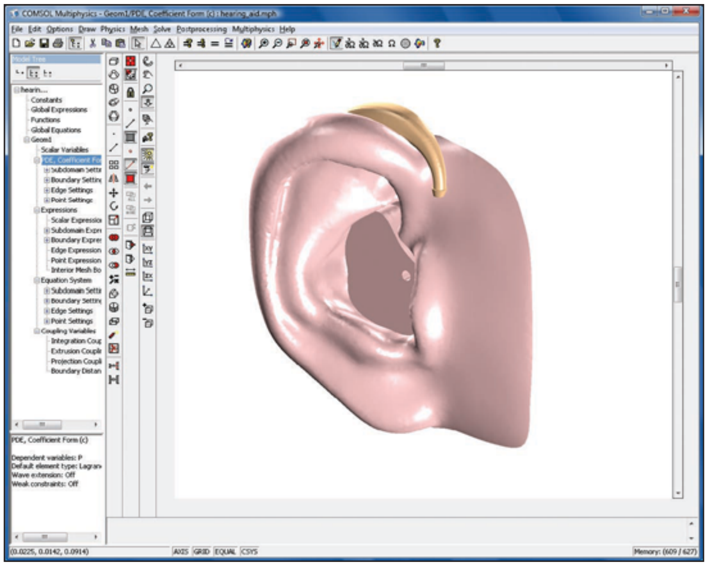

Figure 2: The geometry imported from Pro/ENGINEER® of the ear and hearing aid in the COMSOL Multiphysics. The vent hole in the ear mold is seen in middle of the ear canal.

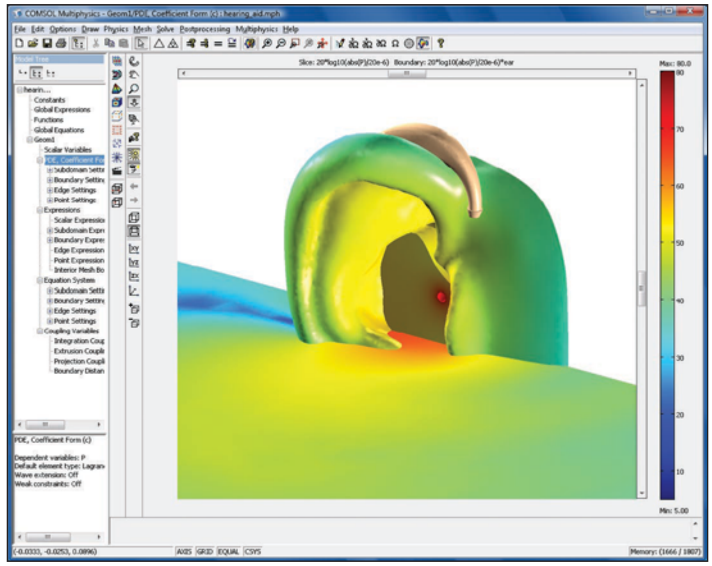

Figure 3: A COMSOL slice plot helps evaluate the ear's shadow effect at 1 kHz. The "shadow" is evident behind the ear.

After using the CAD Import Module to read in the Pro/ENGINEER® CAD drawings supplied by our mechanical design department, we set up the problem in COMSOL's PDE mode. Once we get the COMSOL results, we transfer them to a specialized simulation and algorithm-development environment we have created that is based on MATLAB®. We have found very close agreement between sound-pressure plots from hearing aids using these algorithms and test setups we have constructed using plastic ears.

Studying the Ear's Shadow Effects

With our modeling results, we are starting to improve certain hearing-aid features such as optimizing the hearing-aid's mechanical stability without leading to further feedback along with determining the best place to position the microphones. This has become possible as we now have a tool that allows us to better study the shadow effects of the ear, whereby sound from certain directions is blocked to some extent. We are also using modeling to find the best location of the ear mold's vent hole, which is added to prevent unnecessary attenuation of low frequencies and occlusion. This is when users feel a sense of pressure or blockage whereby they hear themselves (like a singer who places a finger in their ear when performing), hear echoes or even finding chewing food noisy and unpleasant.

Developing a Comprehensive Model

Thanks to our studies with COMSOL, we are gaining a far better understanding of the acoustics of the ear in general, and how it affects the sound field that a hearing aid can measure. We can perform virtual tests on changes to the hearing-aid geometry, and the greater insights we gain into the physics of the system the better we can determine how various parameters interact. And while the current model includes only an ear on a flat surface, we hope that later models will include the entire head to see how it influences the incoming sound. ■

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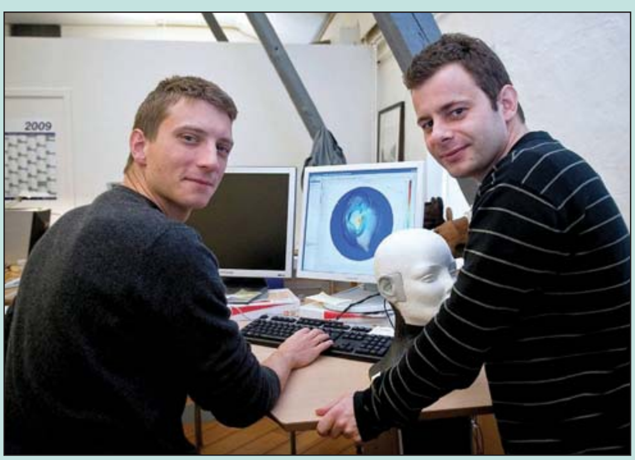
About the Author

Dr. Mads Jakob Herring Jensen has been working in the audiological research lab of Widex A/S (Vaerloese, Denmark) since 2006, and he has been using COMSOL for almost 6 years, first in the field of microfluidics and more recently to implement a thermoviscous acoustic model. He got his MSc in Engineering from the Technical Univ. of Denmark (DTU), moved on to do research at Harvard Univ in the USA, and then returned to the DTU to receive his PhD in the Dept. of Micro- and Nanotechnology.



Mads Jensen (left) and his colleague Lars Friis working at both a virtual and live model of an ear and Widex hearing aid.

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