On the Cutting Edge of Hearing Aid Research

Engineers at Knowles bring the hearing aid industry together to fight feedback with multiphysics simulation.

by GARY DAGASTINE

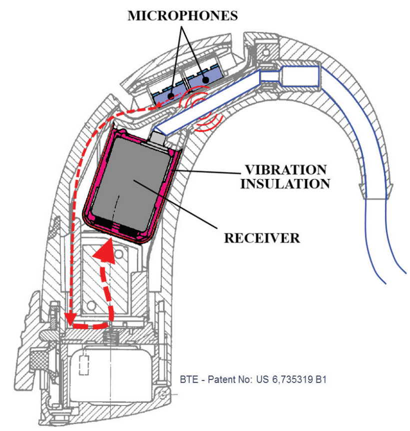

FIGURE 1. A typical BTE hearing aid includes microphones, vibration insulation, and a receiver, among other components. The tight spacing of these components invites troublesome acoustic and mechanical feedback. (Image credit: Knowles Corp.)

In the United States, nearly 20% of the population is reportedly hearing impaired — although that figure could be higher because many people are reluctant to admit they have a hearing problem. Those who are treated rely on miniature and discreet hearing aid devices to improve their hearing, hence their quality of life. Significant R&D effort is required to bring a hearing instrument from a prototype stage to a marketable hearing aid device.

Engineers face daily technical challenges in hearing aid design. Feedback is a major issue that leads to high-pitched squealing or whistling, and limits the amount of gain the aid can provide. "Feedback usually occurs when a hearing aid's microphone picks up sound or vibration inadvertently diverted from what's being channeled into the ear canal and sends it back through the amplifier, creating undesirable oscillations," explains Brenno Varanda, a senior electroacoustic engineer at Knowles Corp. in Itasca, IL.

"For many of Knowles' customers, designing a new hearing aid is a costly, time-intensive process that could take anywhere from 2 to 6 years to complete," Varanda explains. Accurate modeling helps designers select speakers, refine vibration isolation mounts, and package components to reduce the amount of speaker energy that is fed back to the microphone. The industry is in dire need of simple transducer models that will expedite that process, and provide more effective options to consumers. Complete models of speakers and microphones are quite complex, and incorporate many factors that are not necessary for feedback control. "While understanding the electromagnetic, mechanical, and acoustic physics of our transducers is important to transducer designers at Knowles, all of that complexity is not necessarily useful for our customers." Varanda says.

As a global leader and market supplier of hearing aid transducers, intelligent audio, and specialty acoustic components Knowles took a multilateral initiative to develop transducer vibroacoustic models that are easy to implement and compatible with its hearing health customers. The models are intended to help hearing aid designs graduate from a prototype stage to a final product in a more efficient manner without having to sacrifice accuracy.

⇨ HEARING AID DESIGN AND FEEDBACK

When designing hearing aids two major conflicting requirements must be accounted for by engineers. They must be compact and unobtrusive, yet still capable of providing a powerful sound output to overcome the user's hearing loss. The user is far more likely to wear a hearing aid if they are discreet and lightweight. This makes solving the feedback issue more challenging. "A common design challenge is to cram all the hardware components into the smallest space possible without causing feedback instability," Varanda continues.

A typical small behind-the-ear (BTE) hearing aid comprises microphones to convert ambient sounds into electrical signals, a digital signal processor and amplifier to process and boost the electrical signals, and a tiny loudspeaker, also known as a receiver (Figure 1). The receiver, or speaker, "receives" amplified electrical signals and converts them into acoustic energy, or sound, which is then channeled into the ear canal through a tube or an ear mold.

The receiver contains an electromagnetically controlled lever, known as the reed, connected to a diaphragm which generates sound through its oscillating motion. The internal electromechanical forces also generate reaction forces which transmit vibrations through the hearing aid package, creating sound that is picked up by the microphone. This signal in turn is magnified by the amplifier and returned again to the receiver, causing feedback. This path is shown in Figure 1.

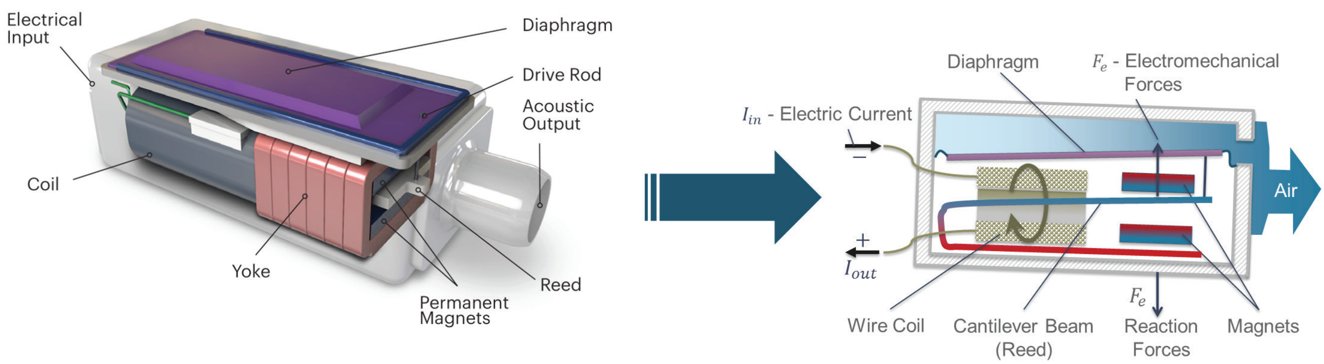

FIGURE 2. A receiver, a key hearing aid component, contains a tiny loudspeaker with an electromagnetically controlled diaphragm that generates sound. Internal electromagnetic forces cause structural vibration that results in mechanical feedback.

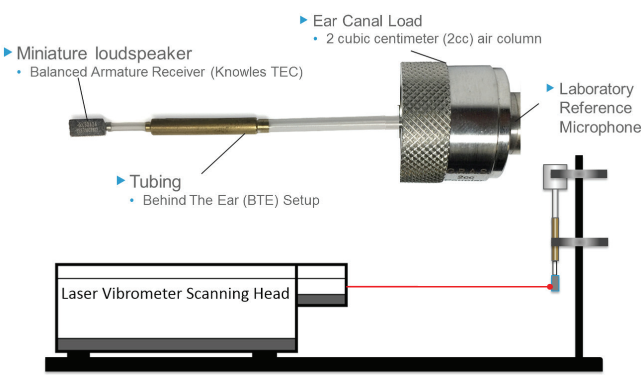

FIGURE 3. Hardware and schematic of the experimental setup.

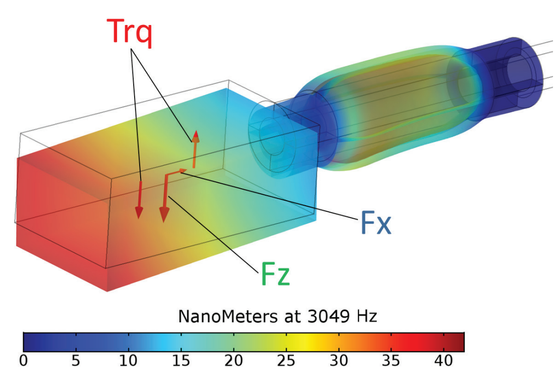

FIGURE 4. Simulation force and displacement results at 3 kHz of the receiver and silicone tube attachment.

⇨ THE "BLACK BOX" MODEL

The receiver's only function is to convert the amplified voltage signal from the microphone into sound. While the construction appears simple, the process is rather complex (Figure 2). The electrical signal is first converted to a magnetic signal, then to a mechanical signal, and finally into an acoustic signal. Each of these steps has its own frequency-dependent characteristics. Understanding the combined effects of all the internal components is vital to the ability of effectively designing receivers for all different hearing aid platforms. Engineers at Knowles have been using complex circuit-equivalents to model all of their internal electrical-magnetic-mechanical-acoustic effects since the 1960s.

Accurately modeling the full complexity of a receiver requires a dauntingly large and complex multi-physics finite element model, making it impractical for fast and efficient hearing aid design. This issue was overcome when Dr. Daniel Warren, a hearing health industry expert in receiver and microphone research, introduced a 'black box' model in 2013. The design uses a minimum amount of simple circuit elements to capture the essential electroacoustic transfer function between voltage and output sound pressure level for balanced armature receivers, while leaving out factors that are unimportant to feedback control.

A key step to simplifying the model was when Warren and Varanda demonstrated that the simplified electroacoustic circuit could be converted into a powerful vibroacoustic model while adding very little complexity to the model. "The conversion is achieved by probing a section of the 'black box' circuit where the voltage across inductors is directly proportional to the internal mechanical forces responsible for structural vibration," Warren explains.

The "black box" and vibroacoustic models needed to be tested and validated against realistic acoustic and mechanical attachments to the receiver before designers could start using them for product designs. A worldwide collaboration between Knowles and its hearing health customers got started in 2014 to validate the models using the COMSOL Multiphysics® software and industry standard tests.

⇨ WORKING TOGETHER ON VALIDATION

To validate the models, engineers needed to measure the acoustic output and vibration forces at the same time, using a structure that could be easily modeled in FEA. Like common hearing aid tests, this test involved connecting a receiver to a short section of tubing leading to an enclosed cavity with a two cubic centimeter (2 cc) volume, which is a standardized ear canal acoustic load as shown in Figure 3. The acoustic pressure inside the cavity is measured with a laboratory-grade microphone. To help verify the robustness of the model, the receiver was also measured using a complex tubing assembly similar to a BTE hearing instrument. The long tubing in this design varies in diameter, and is long enough to support multiple acoustic resonances. At the same time the acoustic output was being measured, the receiver's structural motion was captured by a laser vibrometer. Both translational and rotational motion were measured by observing the motion at multiple points on the surface of the receiver housing.

Warren and Varanda collaborated with several Knowles customers to perform the measurements described above. With the help of COMSOL Multiphysics, they were able to implement the simplified vibroacoustic circuit model into a simulated replica of the test setup described above. The simulation couples the mechanical interaction between the motion of the receiver and the silicone tubing attachment, thermoviscous losses within the various tubing cross sections, and acoustic pressure loads inside the cavity and tubing with the internal electro-magnetic-acoustic effects in the "black box" receiver model.

The COMSOL model revealed the dependence of the output pressure and mechanical forces on the applied voltage, frequency, and material properties. Figure 4 shows the displacement results from the simulation at 3 kHz and the reaction forces coupled to the receiver.

When Varanda compared the results of simulations with the physical measurements, they showed excellent agreement (Figure 5). The forces acting on the diaphragm and the reed are acoustically dependent on the output sound pressure. However, the coupling between the forces acting on the diaphragm with the structural reaction forces proves to be, as expected, directly proportional.

"With multiphysics simulation hearing-aid designers now have the capability to reduce feedback and improve overall performance better, faster, and more economically than before, which will lead to better options for people who are hearing impaired."

⇨ SPREADING THE KNOWLEDGE

Knowles shares their model to empower engineers at other hearing aid companies to solve their own system feedback troubles. With a complete representation of the acoustic, mechanical, and electromagnetic behavior inside the hardware, designers are well set up to virtually optimize their products.

"COMSOL is one of the few modeling and simulation tools that can easily couple the lumped 'black box' receiver circuit with acoustics and solid mechanics," says Varanda. "Until now, verifying and optimizing hearing aid designs has been as much art as science. We will be very happy to see new hearing instruments designs that have benefitted from these models."

By joining forces, the intercompany effort has made it easier for everyone in the hearing health industry. "Ultimately, hearing aid designers don't want to get bogged down with complex transducer models and time-consuming simulations. They simply want focus on their own design and to swap transducers in and out to see how everything will work together," he adds. "This COMSOL model enables them to do this. The behavior of hundreds of transducers can be easily compared for one hearing aid package."

Hearing aid designers now have the capability to reduce feedback and improve overall performance better, faster and more economically than before, which will lead to options for people who are hearing impaired. ❖

Brenno Varanda, senior electroacoustic engineer, Knowles Corp.

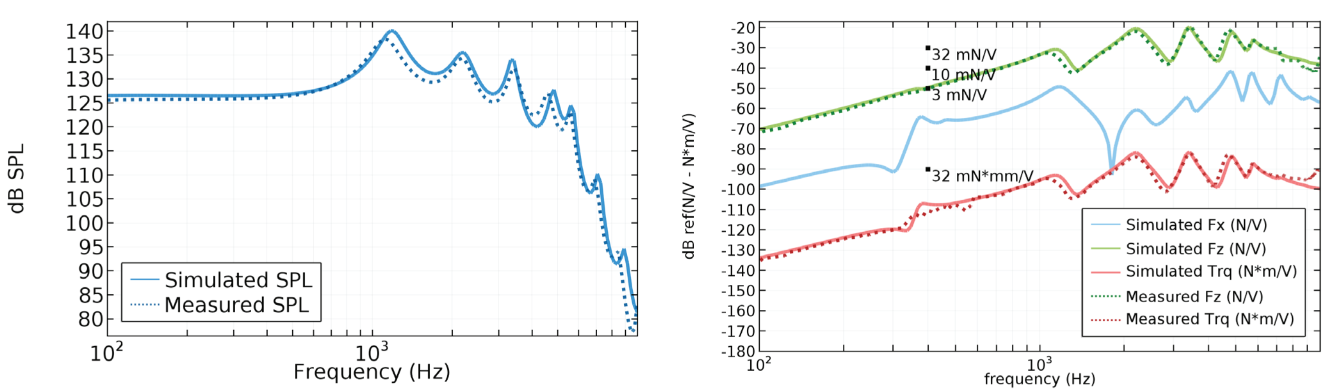

FIGURE 5. Left: Measured (dotted line) vs. simulated (solid line) sound pressure level inside a 2-cc coupler. Right: Measured (dotted line) vs. simulated (solid line) forces and torque acting on the receiver.