Music to Your Ears: New Transducers Meet Electrostatic Headphones

An audio technology startup delivers new manufacturable transducers for high-end electrostatic headphones and reduces low-end roll-off.

By Jennifer Hand

Serious hi-fi enthusiasts get excited about the musical experience delivered by electrostatic headphones. Producing a natural, airy sound, they provide greater clarity, less distortion, and extended bandwidth when compared to other types of headphones where high resolution audio sources are involved.

Most electrostatic speakers apply an electric charge on a thin elastic membrane situated between two conductive plates. The charged membrane moves in direct response to the electrical input, generating the sound waves that our ears and brain interpret as music, and moving us to joy and tears.

Despite their high quality and accurate audio reproduction, electrostatic speakers can be prohibitively expensive, sometimes fragile, and until recently, were handmade because of mechanical precision requirements. Seeing a need for affordable, high-quality headphones that could be manufactured more easily, Warwick Audio Technologies Limited (WAT) designed the High-Precision Electrostatic Laminate (HPEL) transducer, a patented technology based on an ultrathin diaphragm and a single conductive plate instead of a pair. With its origins at Warwick University in the UK, WAT has developed a lightweight laminate membrane only 0.7 mm thick that is perfectly suited for electrostatic headphones.

The new HPELs are lightweight thin-film structures manufactured through a continuous roll process. “The technology we’ve developed is unique,” explains Martin Roberts, CEO of WAT. “The HPEL transducer is made up of a metallized polypropylene film, a polymer spacer with hexagonal cells, and a conductive mesh" (Figure 1).

Figure 1. Left to right: WAT’s HPEL transducers; single laminate, assembled, and exploded views of a finished HPEL transducer. All laminates are made in the UK.

IIn the typical setup, direct current (DC) bias voltage is applied to the elastic membrane and alternating current (AC) drive signal to the surrounding plates. WAT's one-sided speaker involves both the DC bias and the AC drive signal applied to the elastic membrane, with a single wire mesh (plate) positioned opposite the membrane as a ground plane.

The fabrication method makes it possible to reproduce the transducers at a significantly lower cost than traditional electrostatic speakers. This means that for the first time, electrostatics may be considered a commercially viable high-res audio option across a wide range of device types and market segments.

Simulating Acoustic Playback

To develop a transducer like this, which can be easily manufactured and inexpensive without compromising sound quality, the WAT team thoroughly investigated the influence of many design elements before settling on a final version. "We had developed numerous prototypes that clearly performed. The big issue was that we were not entirely sure how varying individual material and design parameters affected the transducer's performance," Roberts says.

The dynamics of the HPEL are dependent on the extremely complex interplay between membrane tension, AC signal level, speaker geometry, elastic and dielectric material properties, thermoacoustic losses, and the added mass effects of the air next to the open side of the membrane. The designers wanted to improve bass performance by reducing low-end roll-off, minimizing distortion, and maximizing the sound pressure level for a given electrical input. But they discovered that small changes to any component greatly affected the acoustic output.

Although WAT had significant mechanical, electrical, and acoustic expertise, they had no in-house simulation capability to help them understand this interplay. In order to perform a virtual optimization of the HPEL transducer design they enlisted the help of Xi Engineering, a COMSOL Certified Consultant that specializes in computational modeling, design recommendations, and solving noise and vibration problems in machinery and other technology.

Dr. Brett Marmo, technical director of Xi Engineering, oversaw the development of the

COMSOL Multiphysics® software models they used to analyze the behavior of the HPEL. COMSOL® software, which allowed Xi Engineering to model nonlinear effects that would arise with amendments to the HPEL's asymmetrical design.

"We kept the early model simple, focusing on specifics that influence sound quality, for example keeping the first harmonic as low as possible to understand the acoustic-structure interaction and the HPEL's performance at low frequency," Marmo explains, describing their preliminary tests. "Our model showed how applied voltage affects signal levels, which helped us understand sound distortion for an initial case."

Because the transducer is one-sided, the electrostatic force varies with the position of the vibrating membrane, decreasing with the square of the distance between the membrane and the mesh. Once they understood the resulting nonlinear distortion and were able to predict its effects, the WAT engineers could then cancel any related distortions electrically.

Perfecting the HPEL Transducer Design

In a more extensive simulation that involved a structural-MEMS-acoustic coupling, he examined the impact of adjusting parameters like the size of the hexagonal cells in the wire mesh, thickness of the wires, membrane tension, spacing between membrane and mesh, and material properties of each component. Marmo and his colleagues also studied the effects of different DC biases, which are often responsible for distortion at low frequencies, and looked at conductivity along the plate to discern whether voltages were higher in one area than another. They then used COMSOL to study the thermoacoustic losses and model the displacement of the membrane for different frequencies (Figure 2).

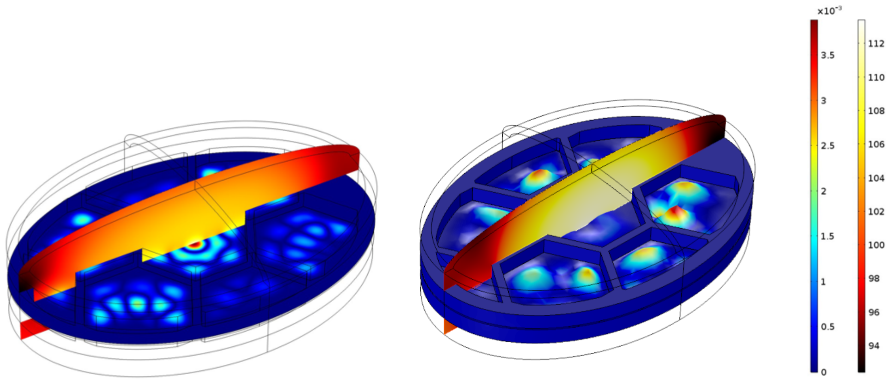

Figure 2. Simulation plot showing the sound pressure level (thermal color surface) in dB and the displacement of the membrane (rainbow color surface) in mm from a fully coupled acoustics-MEMS model solved in the frequency domain. Left: solution at 5,000 Hz. Right: solution at 5,250 Hz.

"We found that this type of simulation was the only accurate way to truly model planar electrostatic transducers," Marmo continues. "For this case, lumped parameter modeling can characterize limited aspects of performance, such as low-frequency amplitude response. One parameter might be excellent but there may be significant distortion created elsewhere. Multiphysics modeling encompasses all dimensions that affect our perception of sound, such as the time-domain response and nonlinear distortion."

The simulations made it possible for the engineers at WAT to tweak design parameters in order to optimize overall performance. Ultimately, they were able to predict what was causing spikes in the frequency response and smooth out the signal for better fidelity.

"This represented a huge cost and time benefit for us," says Roberts. "We went from making multiple prototypes by hand each week to simply dialing up a new one in the software. In addition to settling on a final design we're very happy with, it is now easy for us to customize our transducers for clients' individual requirements."

Marmo's team compared each model with physical measurements provided by the WAT design team. "The simulation results were astoundingly close to the physical measurements," comments Dan Anagnos, CTO at WAT. "That was probably the most exciting aspect, seeing the simulation come to life and knowing it was giving us an accurate picture of how the speaker would perform."

Freedom and Flexibility with a Simulation App

With simulation results verified and WAT satisfied with their design, the next step was for Xi Engineering to put WAT in control of further modeling. The Application Builder available in COMSOL software enabled Marmo's team to build an app from their simulation and host it online.

The app's interface allows users to change certain inputs to test changes to a number of parameters, such as the DC bias, AC signal level, frequency range and resolution, material properties, speaker size, wire mesh shape and size, and spacer placement (Figure 3). The original model setup is not accessible from the app; instead, it allows users to run further tests without needing to learn the software.

“Providing WAT with a simulation app removed the need for them to purchase the software or appoint an experienced user,” Marmo says. “Simulation apps put our customers in charge, so they don’t have to come back to us for small changes and they can test exactly what they want. It also frees us to explore new challenges, rather than working on variations of the same problem.” Xi Engineering expects to use computational apps more and more in the course of its work for other customers.

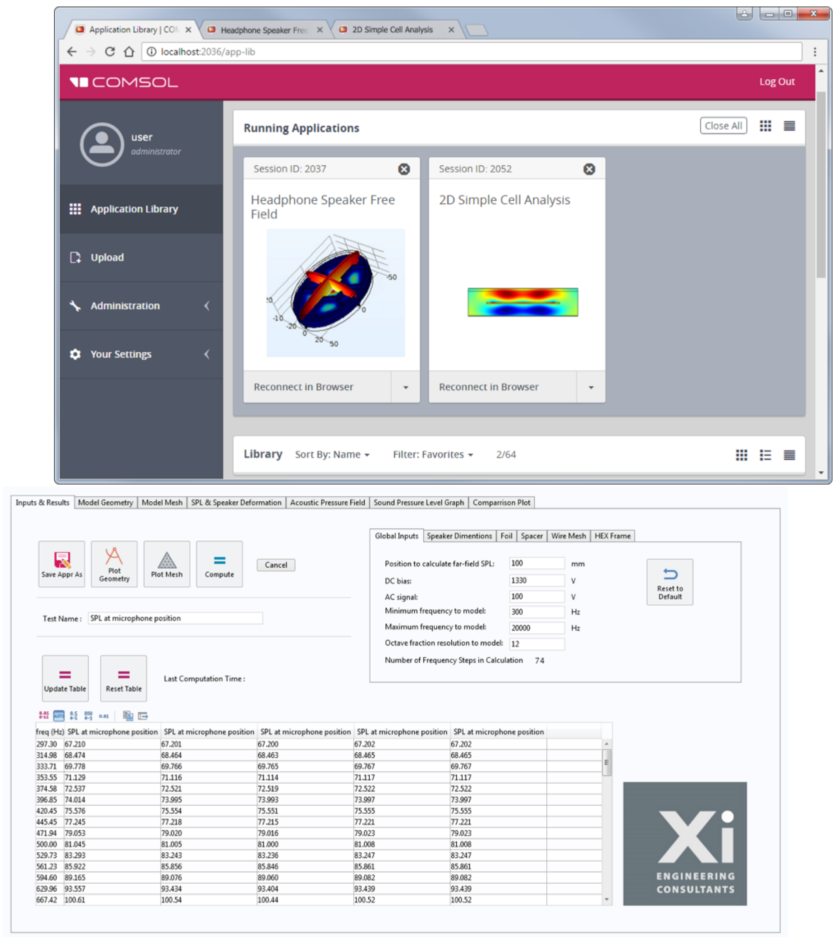

Figure 3. Bottom: The app developed by Xi Engineering allows engineers to vary parameters related to frequency, electrical input, speaker dimensions, and properties of the membrane, spacer, and wire mesh. Results give the sound pressure levels for different cases, membrane displacement, frequency response to different DC biases, and a comparison of the simulated design against experimental results. Top: The app is shared through the COMSOL Server™ product and accessible from a web browser.

WAT is doing the same, sharing the app with their own customers — companies wanting to find the HPEL transducer best suited to their particular headphone designs. “The team at Xi Engineering have been superb. They have deep expertise and helped to unpack the complexity of our product,” adds Roberts. “The intuitive app that Xi developed for us is an additional bonus. Without revealing any intellectual property we can give our own clients access to our design through the app, so they can test and incorporate the technology into their own high-end headphones.”