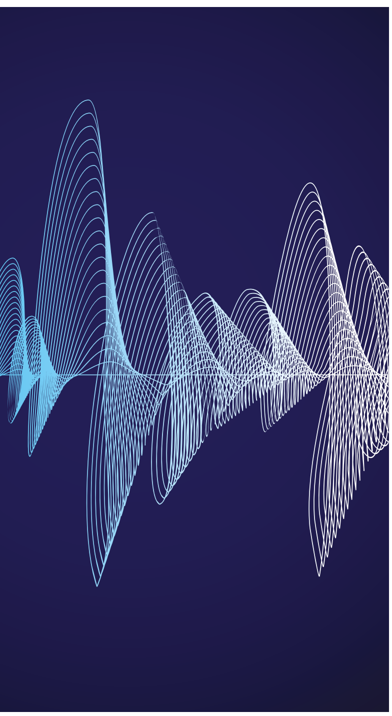
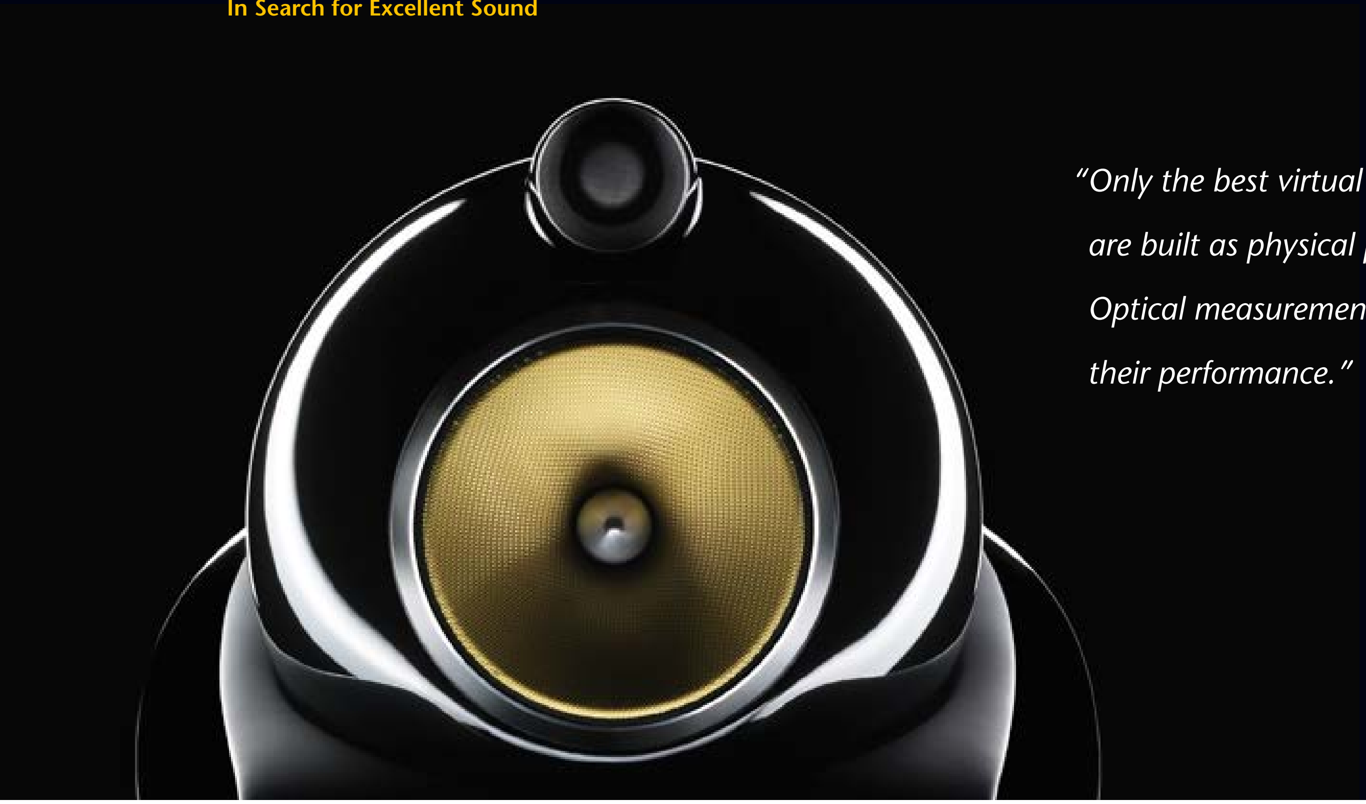


In Search For Excellent Sound

Model Validation for High-End Loudspeakers

Application Note



"Only the best virtual prototypes are built as physical prototypes. Optical measurements validate their performance."

Collaborate to Innovate

How to develop outstanding designs by combining simulations and measurements

B&W Bowers & Wilkins 800 Diamond

The challenge for R&D departments is to be able to immediately respond to their customers' needs and changing markets by accelerating and optimizing product development processes. Their success is a significant factor for a company's competitiveness and requires economic thinking and acting during design processes. Those involve simulations as well as measurements that are typically performed independently of each other. Often, different departments with separate budgets are responsible for these tasks. If both simulations and measurements can be brought together in a way that they complement each other, development cycles are accelerated with increased quality and innovativeness of the product.

Bowers & Wilkins is a company producing audio systems. R&D is a core process in the company's activity. This whitepaper shows how Bowers &Wilkins efficiently combines simulation and measurement to optimize their loudspeaker cabinet design. The engineers in their R&D department use COMSOL Multiphysics for simulations and the Scanning Laser Doppler Vibrometer (SLDV) by Polytec for measurements and combine both in a holistic design process.

The Challenge of Loudspeaker Cabinet Design

For loudspeaker cabinet design it is important that the cabinet itself does not contribute to the total sound radiation. There are three mechanisms that can cause the cabinet to radiate sound and therefore must be avoided or compensated for:

- Sound waves from the rear of the loudspeaker are not in phase with the ones from the front which leads to distortion of the signal due to echoes, time lags and reverberation.
- Vibration of the cabinet due to reaction forces of the electrodynamic transducer, the so-called loudspeaker drive unit, which emits sound.
- Sound waves radiated by the cone inside the enclosure can leak through the cabinet walls by transmission

The subject of research at Bowers & Wilkins was to estimate the acoustic output of the loudspeaker cabinet by using finite element simulations with the objective of improving their designs (Cobianchi & Rousseau, 2014). The investigated loudspeaker system was a B&W 800 Diamond.

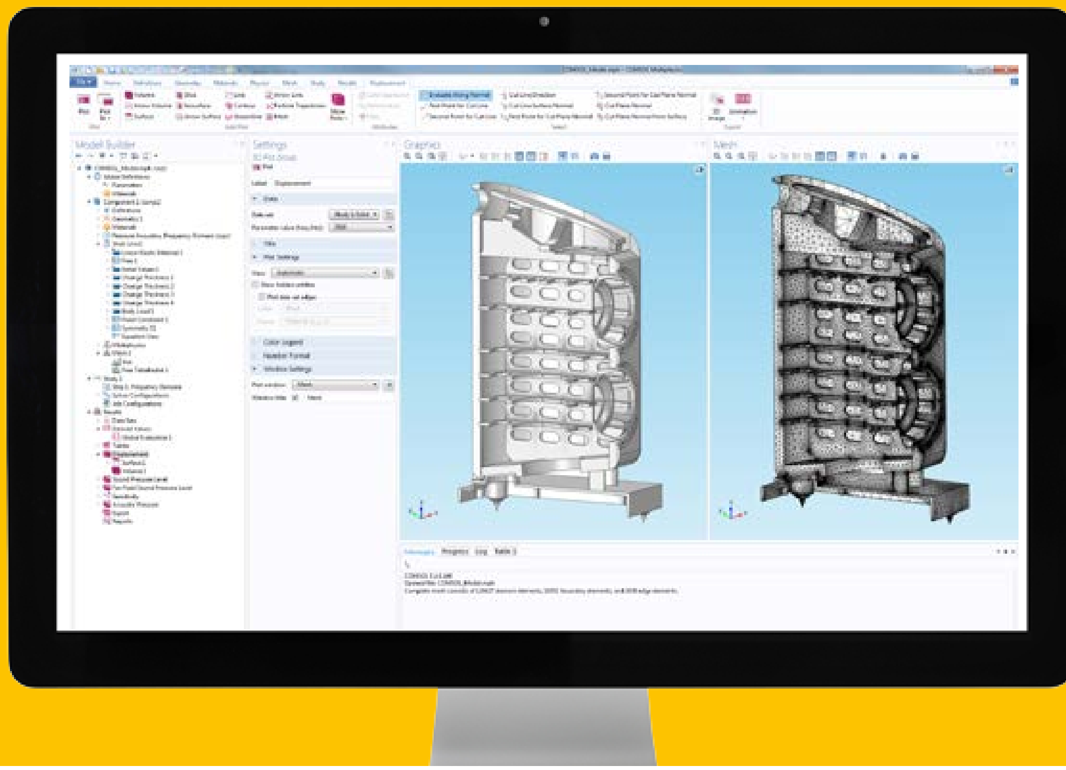
Facing the challenge

Cobianchi and Rousseau used COMSOL Multiphysics to accurately model the vibration and to compare different design options, focusing on the low frequency section of the loudspeaker system. They measured the structure-borne sound of the cabinet with optical scanning laser Doppler vibrometry to validate the simulation results.

The materials that are used to assemble the enclosure are crucial for its quality and performance. Their individual properties and placements influence the acoustic behavior of the loudspeaker cabinet. The important step during the design process is to optimize and test different assemblies and materials with respect to quality as well as costs. Building a prototype to measure its performance is both time consuming and expensive.

Testing each design option is therefore out of the question. Fortunately this task is perfect for a simulation software in which different virtual designs are implemented and materials are changed with just a few clicks. While it is true that one cannot rely on simulation alone particularly if completely new designs or materials are considered it still pays off as only the best virtual prototypes will be built as physical prototypes and measurements will validate their performance or give hints at how to further improve the design.

The investigated B&W 800 Diamond is made of birch plywood for the cabinet wrap, MDF panels, aluminum for the plinth and drive unit chassis, steel and neodymium for the loudspeaker motor, and water based glue joints.



Geometry and mesh of the loudspeaker in the COMSOL GUI.

Turning Design Ideas into Simulation Models – Model Setup

Performing simulations means solving mathematical equations by means of numerical methods. State-of the-art simulation tools have intuitive graphical user interfaces where engineers can select from predefined material properties and suitable domain- and boundary conditions without having to know in detail which equation is implemented in the background or which numerical method is used to solve them. From this point of view, simulation can be done by almost everyone.

However, in order to make the simulation model efficient regarding computation time, memory usage and accuracy, some effort should be spent on the model before starting to simulate: Can symmetry be exploited in the model? Could it somehow be simplified? Are there areas in the model which are more important than others? If yes, the model size can be reduced while the areas of interest can be simulated with higher accuracy. This is where the experience of a simulation engineer comes into play which helps optimizing computation time as well as model accuracy.

From CAD Design to Model Geometry
The final CAD design is the virtual new product and includes all labels, embellishments, and tiny screws. Most of these details will not influence the performance of the product but including them in the simulation will blow up the model size. The first step in the model setup is to import the CAD design into the simulation environment. If available, this should be a version of the design without the unnecessary details mentioned above. Alternatively, the simulation software provides defeaturing tools to clean up the CAD design.

COMSOL is able to communicate with many CAD programs in a way that changes in the design are synchronized with the model geometry immediately. Furthermore, parameters in the CAD design can be controlled inside the COMSOL GUI which enables automatic access to countless different design options. Built-in CAD functionality provides the possibility to edit the geometry subsequently. Figure 2 displays the model geometry and the mesh of the loudspeaker in the COMSOL GUI. Due to symmetry only one half of the loudspeaker is simulated. Cutting and discarding half of the model geometry is built-in CAD functionality.

Realistic Simulations through Realistic Material Properties

Material properties play a crucial role for the simulation. They are often temperature dependent or anisotropic, can depend on their history, or will change completely if a certain criterion is fulfilled (like fatigue or phase change). They are the coefficients of the underlying mathematical equation the simulation will solve.
For vibration analysis the elastic material properties need to be defined. Standard material data, as in this case for aluminum or steel, are available from COMSOL's integrated material database. However, for other materials exact material properties are often unknown, either because they are kept secret by the manufacturers or because they have not been measured yet.

Simulation helps to estimate these parameters based on an eigenfrequency analysis of a sample plate.

The materials used here for the cabinet wrap, plywood and medium-density fiberboard (MDF), are a mix of woods and resins. Plywood consists of different layers where the wooden fibers have different orientations and material properties depend on this orientation. Simulation enables the R&D engineers to consider these anisotropic material properties. Eigenfrequency analysis provides the set of elastic constants which are then used for the loudspeaker wrap as equivalent orthotropic material. As the wrap is curved a coordinate system following this curvature is used to define the orthotropic properties. Damping properties are also included and were estimated using a modal analysis fitting technique.

To model the glue joints which are small compared to the whole geometry, special boundary conditions are used to represent the joints rather than implementing them in the geometry. This helps to keep the computational size of the problem small while maintaining accuracy.

Analyzing Cabinet Performance

After this preliminary work is done the vibration of the whole enclosure is studied. The results do not represent the acoustic output directly but on its basis the post-processing functionality in the simulation environment provides the possibility to compute acoustic pressure or acoustic power by numerical integration according to well-known approximations like the Rayleigh integral. Comparing the spectra of the Rayleigh integral to that of the cabinet wall acceleration shows that all vibration modes also radiate sound.

So far, the model assumes a uniform force from the transducer motor, but in reality it is frequency dependent because of two phenomena: the single degree of freedom oscillator behavior representing the transducer, and the electrical network put between the loudspeaker terminals and the drive units to divide the audio frequency spectrum across the different drive units in charge of reproducing each frequency band. In this case so called transfer functions can be applied to the results to process the output quantities and match the reality. These transfer functions are calculated from an electromechanical model that relates the applied voltage to the motor output force.

Measurement setup

Validation through measurements is inevitable before a new design is ready for production. A prototype based on simulation results is produced and measurements are performed to confirm its quality or to find potential for improvement.

To measure vibrations of loudspeakers a non-contact method is essential and laser Doppler vibrometry is a standard method which returns the velocity and/or acceleration of the vibrating surface. The distribution of these quantities over the cabinet walls can be directly compared to the simulation results. But they do not necessarily describe the performance of the cabinet in terms of radiated sound. To validate the results from the simulation performed in the first phase, the surface velocity and the respective deflection shape was probed with a non-contact scanning laser Doppler vibrometer (SLDV).

Polytec's PSV-500 scanning vibrometer for non contact measuring of structure vibration.

“Non-contact measurement technology with high spatial resolution is essential to capture the product’s performance.”

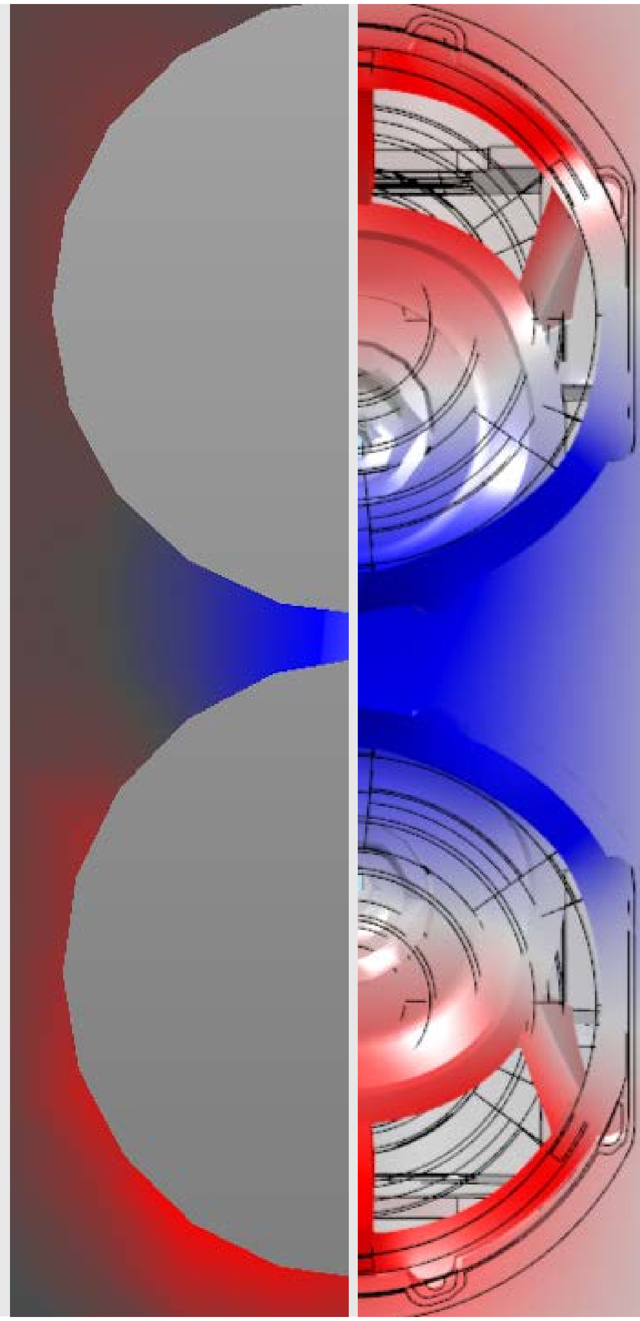
Innovative measurement technology for an innovative product

Non-contact and full-field vibration sensing technology allows to probe with the spatial resolution required for a meaningful validation of the simulation results. Thanks to the automatic sequential scanning procedure the instrumentation effort does not change with increased measurement grid resolution. Conventional mounting of accelerometers would mass-load the structure and typically leads to loss in linearity due to coupling resonances. The SLDV detects the surface velocity without changing the mechanical properties of the cabinet. For the validation bandwidth of 10 kHz the flat frequency response of the laser Doppler vibrometer is beneficial as light does not experience coupling resonances.

The measurement grid can either be imported from the simulation model geometry or manually defined. To take into account phase relations between all measurement points, the driving voltage phase of the drive units is used as a phase reference.

The two largest and thus most important radiating surfaces are the front baffle and wrap. The velocity of each point on a user-defined grid over these surfaces was measured with the laser Doppler scanning system developed by Polytec.

Measurements confirm simulated cabinet performance



Measured modal shape at 222 Hz (left) and simulated modal shape at 281 Hz (right).

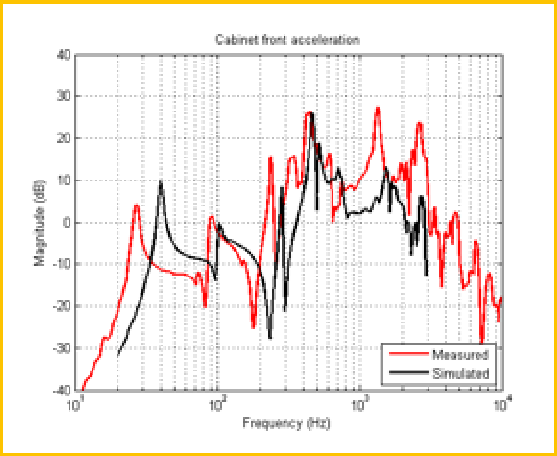
Validation is done by comparing the measured acceleration magnitude spectra to the simulated values at critical locations. To facilitate this comparison, the finite element mesh from COMSOL was used as measuring grid for the Polytec laser. Figure4 shows the modal shape for the first relevant mode.

Simulation identifies the main regions of significant peaks which are related to rigid body motion, plate bending modes of the plinth and modes related to the front baffle and side wrap.

While the vibration amplitudes agree well between simulations and measurements, the associated frequencies were overestimated by the simulation, as displayed in Figure 5.This discrepancy can be related to assumptions made in the simulation model, like the choice of boundary conditions or the description of material properties as bulk properties.

The development engineers of B&W are confident that they could improve the match of results with an improved model. But they also have to raise the question if an improved simulation model will result in an improved cabinet design, not only with respect to quality, but also with respect to development cost and time.

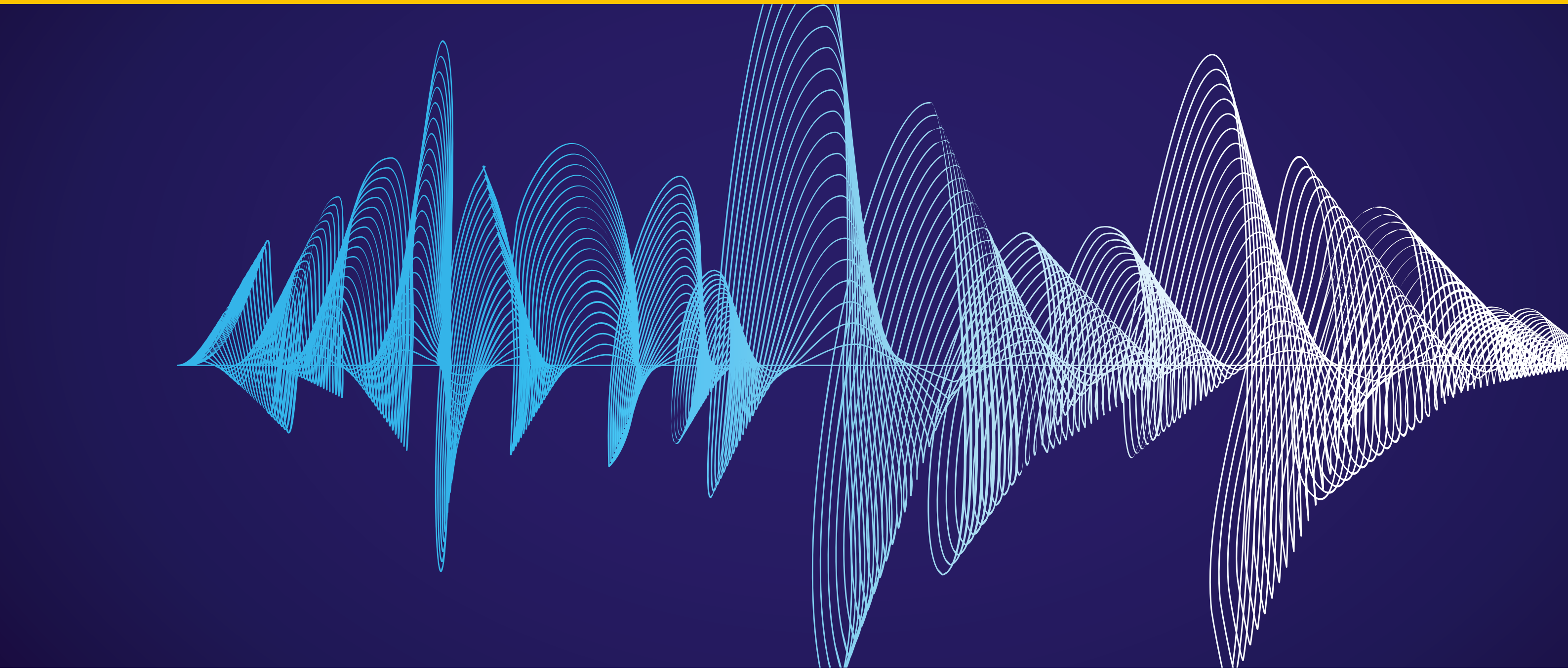
Within the scope of this work, they concluded that the simulation results are sufficient to predict the quality of the modeled cabinet design. The simulation also provides insight into physical effects which in this case leads to better understanding of how different vibration modes couple and how different panel placements affect the cabinet's performance.



Cabinet front acceleration as a function of frequency from simulation (black line) and measurement (red line).

Conclusion

"Simulations are images of reality, measurements are observations of reality. Combining both methods reveals the full information about the system."



Simulations are images of reality, providing a set of physical parameters at each grid point. Their accuracy is limited by the accuracy of the underlying mathematical model, the accuracy of the input parameters and the numerical method as well as computational effort. Measurements are observations of reality. They reveal effects that may not have been included in the simulation but need working prototypes as observable objects. Apart from measurement errors, some quantities are not accessible by measurements, and not every observed effect can be readily explained as it might be difficult to control the measurement conditions.

Only the combination of both methods can reveal the full information about the system: The comparison of the model with measurements can help to identify the relevant and dominant physical phenomena involved and therefore to get a deeper understanding of the system behavior. Understanding that can guide the design effort.

Once the set-up of a single model capable of reproducing all relevant data within the required accuracy is done, it can be used to batch-process all the design options and material choices automatically.

For future projects, vibration measurements could be used for models of acoustic propagation. The measured velocity distribution would be used as the input in a purely acoustics model. Then, the sound pressure in any point in space produced by a sound source with arbitrary surrounding objects and acoustic environment can be predicted by the simulation software. Such an approach to the propagation problem would be eased by exchangeable data formats between simulation software and measurement equipment. Both COMSOL Multiphysics and Polytec provide the technology to realize this project.

B&W Bowers & Wilkins

About Bowers & Wilkins

"Bowers & Wilkins is a leading British manufacturer of high-end audio equipment. It was established in 1966, and has since grown to become a globally respected brand. As well as providing popular and award-winning home speakers, Bowers & Wilkins reference-level speakers are found in the world's finest recording studios, including Abbey Road Studios in London and George Lucas's Skywalker Sound in California. As well as loudspeakers, Bowers & Wilkins is increasingly recognized as a leader in wireless speakers, headphones and premium in-car entertainment systems.

COMSOL

About COMSOL

The COMSOL group provides multiphysical simulation software for product design and research to technical enterprises, research labs, and universities. It has 22 offices and a network of distributors all around the world. Its flagship products, COMSOL Multiphysics® and COMSOL Server™, are software environments for modeling and simulating any physics-based system and for building and distributing applications. Add-on products expand the simulation platform for electrical, mechanical, fluid flow, and chemical applications. Interfacing tools enable the integration of COMSOL Multiphysics simulation with all major technical computing and CAD tools on the CAE market.

The integrated software environment which allows for the modeling of different phenomena and for building apps in one graphical user interface makes modeling and simulation available to everyone.

Polytec

About Polytec

Polytec is specialist in optical measurement technologies and laser-based solutions for more than 40 years. Based in the southwest of Germany and with 380 employees worldwide the company offers proven and precise instruments for all branches. Polytec is leading in non-contact laser vibrometry equipment, thus supporting customers to maintain their own technical leadership.

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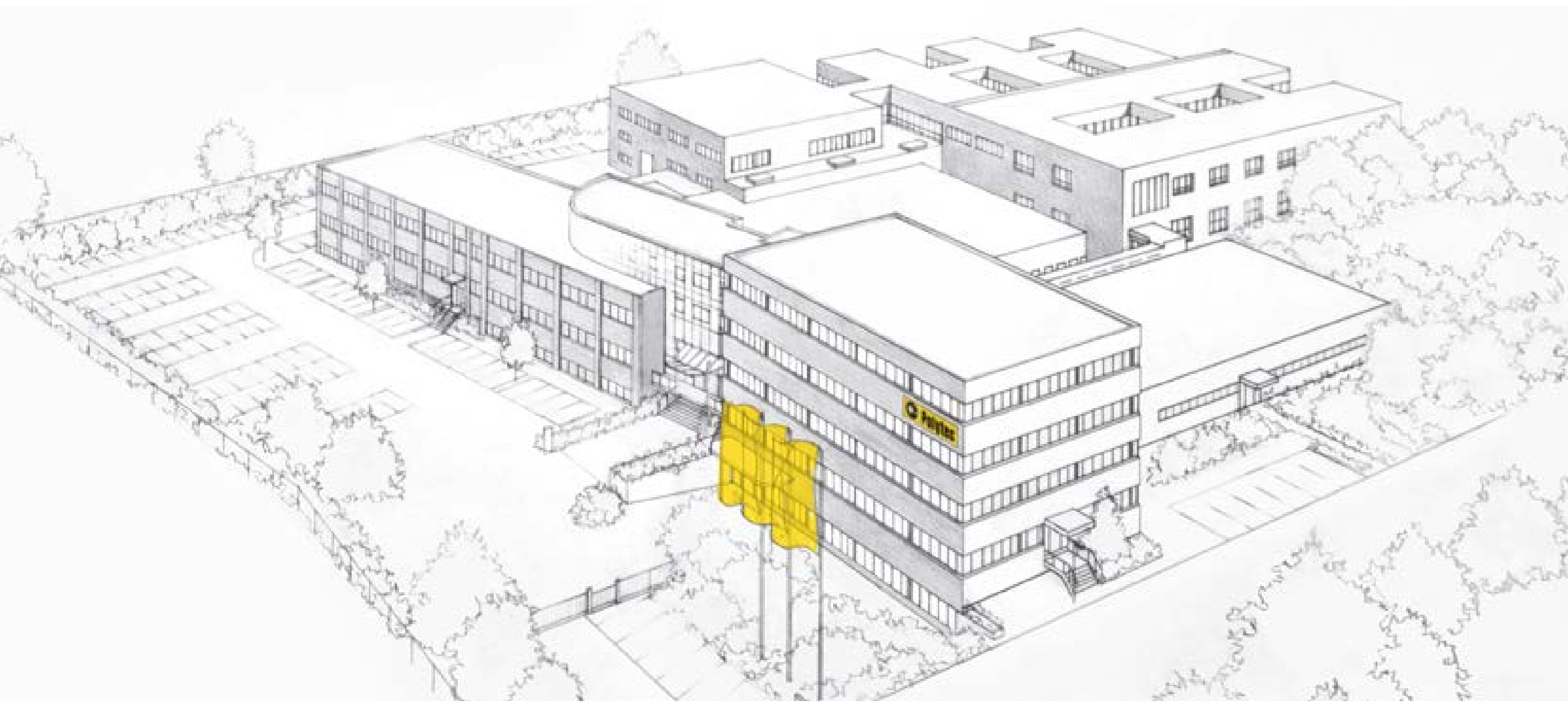

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