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DMP-SMP Parallel Computation Strategies for FE-BEM-PEM Transmission Loss Simulation in Automotive Dash Panels

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Transmission Loss (TL) is a key performance indicator for automotive components such as dash panels, where both structural dynamics and multilayer acoustic treatments contribute to airborne noise insulation. While flat and curved panels have been widely investigated, configurations incorporating poroelastic trim materials remain more complex due to strong coupling between structure, porous media, and surrounding fluid. Conventional approaches such as FEM and SEA present intrinsic limitations: FEM becomes prohibitive at high frequencies due to mesh refinement requirements, whereas SEA relies on statistical assumptions that reduce accuracy for localized resonances and detailed trim layers. A more robust solution is offered by deterministic simulations combining FEM for the structure, PEM for poroelastic materials, and BEM for external radiation. This FE–PEM–BEM approach is based on the mixed displacement–pressure (U, P) formulation introduced by Atalla and collaborators, which has been extensively validated for modeling sound packages and transmission loss in automotive components. Within this framework, the acoustic domain is described through the Helmholtz integral equation, enabling accurate representation of radiation and coupling effects. The formulation also allows precise modeling of baffled configurations and boundary interactions, which are essential for TL predictions. To validate the methodology, a trimmed flat panel benchmark is analyzed using a shell representation for the plate, a 3D poroelastic mesh for the foam, and boundary elements for the acoustic field. Experimental data from an ISO 15186-1 transmission loss setup serve as reference. The FE–PEM–BEM model captures low-frequency behavior dominated by structural flexibility and shows excellent agreement with measurements over the full frequency range. This highlights the limitations of simplified methods such as TMM or SEA in predicting subsystem responses when poroelastic treatments and geometric details play a significant role.

The workflow is then applied to a full automotive dash panel, shown in Figure 1, modeled in its bare form and with multilayer acoustic treatment. The trimmed configuration includes a poroelastic foam layer, a viscoelastic layer, and an adaptation airgap connected to the BEM radiation domain. Coupling between PEM and BEM is implemented through pressure continuity and is independent of mesh matching. The bare configuration retains the same structural–PEM–BEM topology but with simplified material definitions. Simulation results show that trim effects become dominant above 1 kHz, with improvements of up to 30 dB in TL, confirming the relevance of poroelastic modeling in mid and high frequencies.

Given the scale of the model, nearly one million poroelastic elements and tens of thousands of BEM elements, efficient HPC strategies are essential. A hybrid DMP–SMP approach is introduced: frequency-domain decomposition distributes independent frequency tasks across nodes, while multi-threading accelerates local operations such as matrix assembly and H-matrix compression. The performance improvements are shown in Figure 2, where SMP/DMP hybridization outperforms the use of either strategy alone. Hierarchical matrices (H-matrices) further reduce memory usage and computational time, enabling simulations up to several kilohertz without compromising accuracy.

This combined numerical and parallelization strategy allows engineers to evaluate multiple design alternatives per day, significantly improving development efficiency for acoustic trims and dash panel architectures.

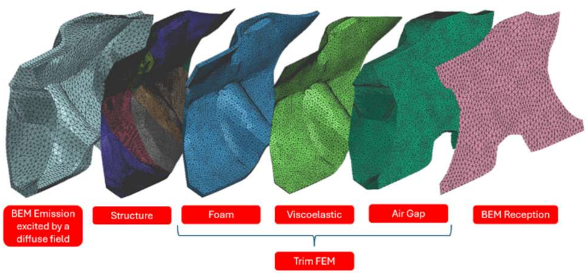

Fig. 1 Trimmed dash panel

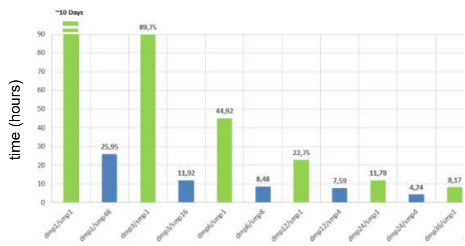

Fig. 2 Elapsed time for a hybrid SMP/DMP on a single node