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Efficient NVH Integration of EDUs Using Hybrid Dynamic Sub Structuring Approaches

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The transition from internal-combustion to electric powertrains removes the broadband masking noise formerly generated by combustion engines and thereby exposes high-frequency, tonal NVH phenomena originating from the electric drive unit (EDU) and inverter. At the same time, accelerated development cycles limit the availability of early full-vehicle prototypes, increasing the need for robust virtual NVH prediction. To meet this requirement, OEMs and suppliers increasingly apply hybrid, component-based modelling approaches that combine experimentally derived substructures with CAE data. Frequency-Based Substructuring (FBS) and blocked-force formulations—standardized in ISO 21955 and ISO 20270—now allow reliable prediction of EDU noise contributions even before hardware prototypes exist, and are supported by all major NVH software environments.

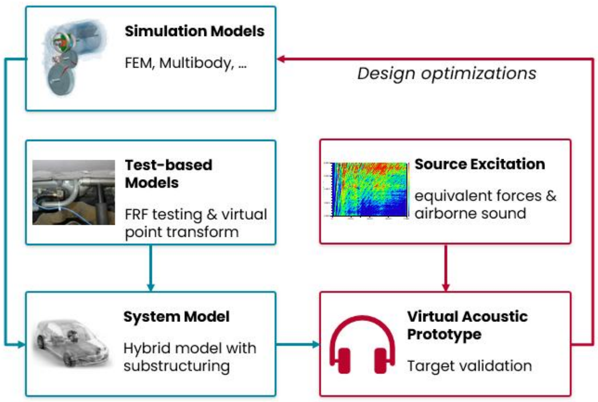

Figure 1 Data flow for flexible NVH simulations in all development phases

Because BEV architectures differ fundamentally from legacy platforms, NVH target setting can no longer rely on historical extrapolation. Benchmark-derived substructures such as vehicle bodies, mount transfer characteristics and blocked-force source descriptions provide a more stable basis for early digital NVH models. Standardized 6-DoF interfaces enable rapid assembly of these models, supporting two main use cases: EDU suppliers can integrate their units into representative vehicle structures to quantify design changes and benchmark performance, while OEMs can establish early digital NVH twins to evaluate architectural options and continuously incorporate CAE and early hardware data.

FBS enables the coupling of heterogeneous substructures by enforcing kinematic compatibility and force equilibrium in the frequency domain. Accurate coupling requires full 6-DoF interface FRFs generated via the Virtual Point Transformation (VPT), which also provides structured quality checks such as mode-shape inspection, signal-integrity verification, physical admissibility and reciprocity assessment. Rubber mounts are characterized as 12-DoF substructures; fixture effects are removed via inverse substructuring or FBS-based decoupling. Their frequency-dependent stiffness—including the strong rise above 500 Hz due to internal resonances—must be retained for realistic EDU noise prediction.

Structure-borne source descriptions follow component-based TPA methodology, preferably using 6-DoF blocked forces; pseudo-forces provide an alternative when mounting points are inaccessible. Airborne excitation is described either operationally in-vehicle or by sound-power measurements and equivalent acoustic monopoles on a semi-anechoic test bench. All source models undergo stringent validation procedures, including on-board reconstruction, XDOF analysis and interface-completeness checks.

After coupling all substructures, the predicted EDU-only driver-ear spectrum is combined with benchmark-derived rolling- and wind-noise scatterbands. Psychoacoustic thresholds allow assessment of the perceptual relevance of tonal components, while time-domain auralization supports subjective evaluation and early concept refinement.

Overall, the hybrid NVH substructuring framework fills a critical gap in modern BEV development. By integrating benchmark-derived receiver models, high-fidelity mount descriptions and ISO-conform source models with CAE data, reliable NVH predictions become available at very early stages. OEMs can define and refine NVH targets and maintain digital NVH twins throughout development, while EDU suppliers can assess the perceptual impact of design measures and perform objective competitive benchmarking. Embedded within FEV's global benchmarking program, this approach reduces development risk, accelerates decision-making, and provides a scalable, data-driven foundation for NVH optimization across the entire vehicle lifecycle.