# Prediction of Vehicle Interior Noise in High Frequency Range using Statistical Energy Analysis Hybrid Method

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## Introduction

The Statistical Energy Analysis (SEA) is a powerful method for predicting the ensemble average response of coupled subsystems with random properties. Although the SEA was developed in the early 60s [1], its importance for the vehicle industry has grown in the last few years.

This paper describes the hybrid approach for SEA (Hybrid Method) and its common implementation in the early stage of the vehicle development. The advantages of this method and the quality of the obtained results are shown in the example of a passenger car.

## Hybrid Method

The Hybrid Method describes how loss factors in and between subsystems can be predicted from Finite Element (FE) models by using the Power Injection Method (PIM), a technique which is typically used to derive loss factors from experimental data [2]. Basically, PIM is based upon the excitation of each subsystem in order to quantify the injected input power and response energy of all subsystems. Each subsystem is excited through a sufficient number of excitation points. From each excitation point a number of response data are provided. Similar to obtaining the experimental data, PIM can be carried out by FE simulation. The FE model (Figure 1) is based on the crash model of the passenger car, which was adapted for the NVH calculation [3].

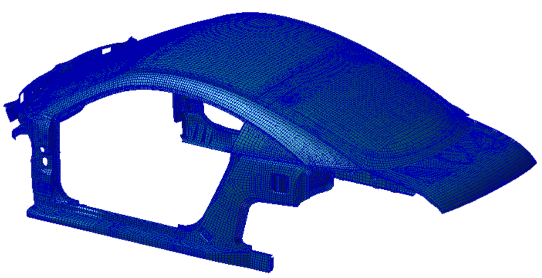

**Figure 1:** Finite Element model of some parts of the vehicle (subsystem roof with adjacent subsystems) for the calculation using Hybrid Method.

From the acceleration results obtained with modal frequency response calculation (MSC NASTRAN), the analyses of the loss factors were carried out using LMS ESEA. In Figure 2 the values of loss factors for the roof and adjacent subsystems are shown in the 1 kHz third octave frequency band. The internal loss factors are placed in the diagonal, the coupling loss factors are off- diagonal.

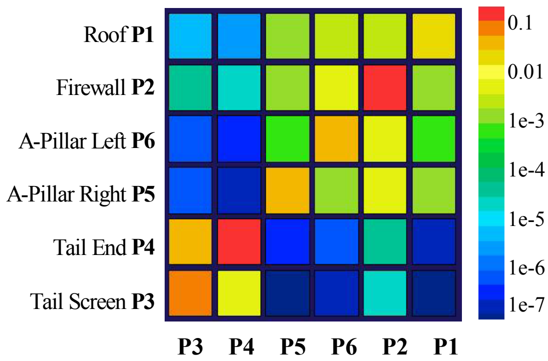


**Figure 2:** Internal and coupling loss factors: values for the vehicle roof with the adjacent subsystems at the 1 kHz third octave frequency band. The values are presented in the logarithmic scale.

An advantage of the Hybrid Method is identifying the tunnelling effect, which means that physically not connected subsystems appear as coupled to each other. An example, observing loss factors of left and right A-pillar is shown in Figure 2. Although they are not physically connected, they have a relatively high coupling loss factor (green coloured).

## Quality of Calculated Results

To check the quality of the calculated results, measurements were performed using the PIM method. The comparison between measurements and calculated results was carried out on the vehicle trimmed body.

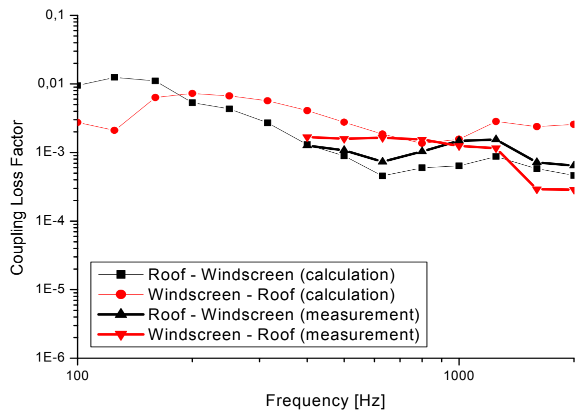


**Figure 3:** Comparison between measured and calculated coupling loss factors for the roof and windscreen for the trimmed body of a passenger car over the frequency.

The internal loss factors correspond to the damping of the particular subsystem and are used as input for the finite element simulation. In this case the comparison with the measurement results is good. On the contrary, the coupling loss factors depend on the connection type, and cannot be determined straightforward. An example of agreement between calculated and measured coupling loss factors for the windscreen and roof is shown in Figure 3.

## Number of Response Data

For stable results and limited calculation effort, it is essential to know how many response data have to be calculated. An investigation of internal and coupling loss factors for 1, 5, 10, and 20 calculated response points and 3 excitation points on each subsystem was carried out. It was found that the internal loss factor results with 3 randomly distributed excitation points on each subsystem already become stable with 5 response points. Thus, with 3 randomly distributed excitation points, the results for coupling loss factors do not converge to negligible differences before 10 response points (Figure 4).

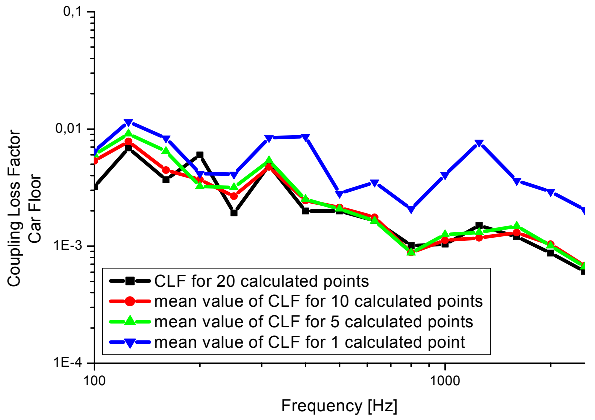


**Figure 4:** Coupling loss factors for different numbers of response data. With more than 10 response data per subsystem the difference between results becomes negligible.

## Size of Finite Element Model Cut-out

As the calculation effort limits both the frequency range of application and the model size, it is a key point to reduce the number of subsystems required for each calculation without reducing the quality of loss factor results. For this target, different cut-out areas of the entire vehicle model were analysed.

In Figure 5 the comparison of coupling loss factors between firewall and right longitudinal cantilever are shown comparing results for two different cut-out areas of FE models. Firstly, the FE model includes the whole front car, secondly, the FE model includes only two subsystems of interest: firewall and right longitudinal cantilever, with its connection. The very good agreement between both cut-outs of the FE models (Figure 5) proves that only two subsystems of interest have an effect on their coupling loss factors. In accordance with the general idea of SEA, presuming the effects of global behaviour can be neglected compared to local behaviour, it is shown that adjacent subsystems can be neglected. This conclusion becomes even more important for the implementation of the Hybrid Method into optimisation processes, where under similar conditions modular building and optimisation of vehicle components are favourable.

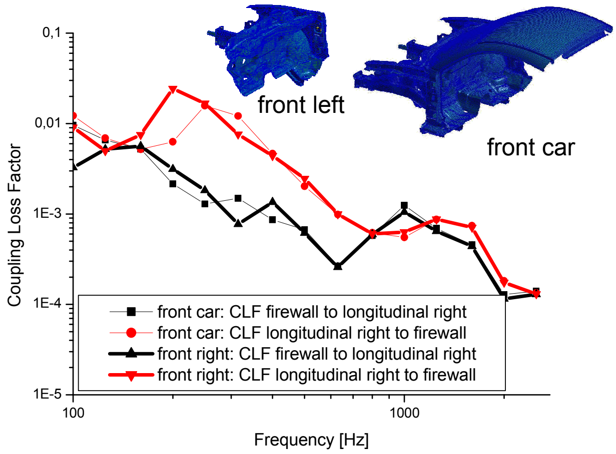


**Figure 5:** Coupling loss factors for firewall and right longitudinal cantilever. Comparison for different variants of the FE model cut-out area.

## Conclusion

The Hybrid Method can be successfully used in the early vehicle development stage to determine loss factors of the individual components from FE models. It allows assessing design variants before hardware of new products is available. Furthermore, it reduces test expenses. The Hybrid Method allows the determination of accurate SEA model parameters for complex subsystems and complex junctions. This paper shows recommended numbers of response points with 3 randomly distributed excitation points per subsystem. For unknown systems, the detection of the tunnelling effect does not increase the computational effort significantly. Last but not least, the advantage of the Hybrid Method is that it can be implemented into the optimisation process using only two subsystems for determining loss factors.

## Acknowledgements

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