

Frontloading Approach for Sound Package Design for Noise Reduction and Weight Optimization Using Statistical Energy Analysis

Vishal Vasantryao Chaudhari, V Radhika, and R Vijay
Mahindra & Mahindra, Ltd.

ABSTRACT

First time right vehicle performance and time to market, remains all automotive OEMs top priority, to remain competitive. NVH performance of product communicates impression to customer, remains one of the most important and complex attribute to meet, considering performances to be met for 20 Hz -6000 Hz. Frontloading techniques (FEM/BEM/SEA/MBD) for NVH are critical and necessary to achieve first time right NVH performance.

Objective of this paper is to present a frontloading approach for automotive sound package optimization (absorber, barrier and damper elements) for SUV vehicle. Current process of designing sound package is mainly based on experience, competitive benchmarking of predecessor products. This process (current process) heavily depend on testing and validation at physical prototype and happens at later stages of program, especially on tooled up body. This is because, structure borne noise development, sealing and leakage path treatment refinement assume priority over sound package development. This way of working has impacted on validation timelines, late changes in peripheral system, leading to cost increase and time delays. High frequency simulations (using statistical energy analysis) provides opportunity in terms of being able to evaluate design options and frontload sound package design in parallel with structure borne NVH development.

In this exercise, SEA (statistical energy analysis) was used to predict full vehicle cabin noise (400 Hz-6000 Hz) by modelling all major paths (structure borne and air borne) present in vehicle. All major sources of excitation such as powertrain vibrations, suspension vibrations and engine bay noise, tyre patch noise, exhaust noise were used to predict cabin noise. Static and dynamic load cases were used to validate modelling confidence and model updating. Contribution analysis was used to identify dominant sources, transfer paths for optimization of sound package for performance and weight.

CITATION: Chaudhari, V., Radhika, V., and Vijay, R., "Frontloading Approach for Sound Package Design for Noise Reduction and Weight Optimization Using Statistical Energy Analysis," *SAE Int. J. Veh. Dyn., Stab., and NVH* 1(1):2017, doi:10.4271/2017-26-0222.

INTRODUCTION

In today's automotive marketplace, fuel economy performance and cost are the significant challenges that most companies face. These attributes have to be delivered to the customer along with refinement and designed to differentiate product from the competition. NVH performance is a key attribute towards providing a refined experience to the customer. It is sufficiently complex, being a dynamic phenomenon, and encompasses a wide frequency range spectrum from 20 Hz - 6000 Hz. It is extremely prohibitive in implementation and cost for NVH design actions to be incorporated in the later stages of product development. Hence front-loading initiatives assume great importance in providing a design that meets functional and cost targets. Techniques such as finite element methods (FEM), boundary element methods (BEM), statistical energy analysis (SEA) and multi-body dynamics (MBD) for NVH analysis are critical and with which first time right NVH performance can be achieved.

This paper presents on a front loading approach for automotive sound package optimization using SEA. Currently, development of sound package mainly involves benchmarking, hardware evaluation of competitor or predecessor vehicles. Due to this, actual sound package development is done through validation on prototypes, at later stages of the vehicle development. This has an impact on the product delivery time lines which requires late changes in the vehicle system, leading to cost and time risks. SEA based high frequency simulations enable sound package development at design stage in parallel with structure borne NVH development. This ensures the development of a concept sound package even before the physical prototype is available.

SEA model of a full vehicle is built for predicting the cabin noise. Major noise sources such as powertrain, tyre patch, exhaust and vibration sources such as powertrain, suspension vibrations are included in the model [1]. The model is then analyzed for static and dynamic load cases. Predicted results are validated with test results. Contribution

analysis is performed for determining the dominant sources and transfer paths for the predicted cabin noise [3]. Based on contribution analysis, sound package optimization is done for performance and weight.

FRONTLOADING APPROACH FOR SOUND PACKAGE SIMULATIONS USING STATISTICAL ENERGY ANALYSIS

Automotive sound package is a combination of absorber, barrier and damping materials. Primary function of absorbers is to dissipate the acoustic energy by friction within the absorptive material. Function of a barrier is to restrict sound propagation through mass-law effects. It is observed that the effective range of the absorber and barrier construction used in the vehicle under study is from 400 Hz - 6000 Hz. Damping treatment such as melt sheets are used on sheet metal panels to cause reduction in vibrational energy through heat dissipation based on its visco-elastic properties.

The SEA method provides an unique advantage in the analysis of noise for the frequency range of 400 Hz-6000 Hz. SEA is a method for studying diffusion of acoustics and vibration energies in a system. It uses statistical description of local modes of the subsystem of a main system and flow of vibrational energy between coupled subsystems proportional to difference in modal energies [2]. The principle of conservation of energy is used to derive a set of power balance equations, which govern the response of the system in a given frequency band. Power balance equation is obtained as per figure 1.

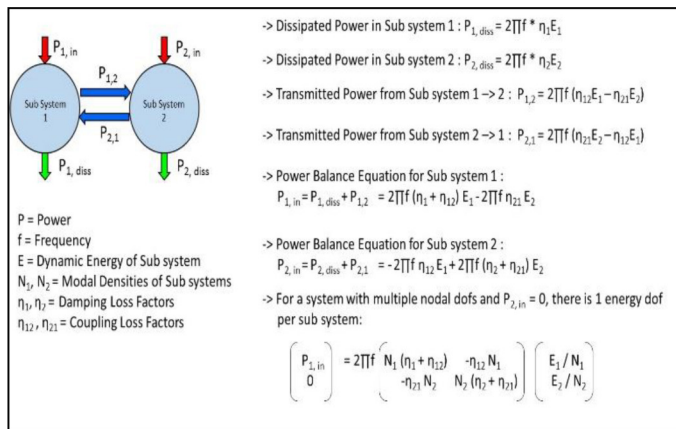


Figure 1. Power balance equations between SEA subsystems

MAJOR TRANSFER PATHS AND SOURCES

An existing MAHINDRA SUV is used to establish and validate the SEA process. Two major noise evaluation tests are simulated. The first test simulates a condition dominated by powertrain noise, which is a wide open throttle gear runup. The second test simulates a driving condition with dominant road induced NVH. This test is a cruising condition at a constant speed of 100 kmph.

Transfer Paths

All major paths from excitation locations to passenger ear are modeled. These paths include the following:

1. Powertrain noise from engine compartment to cabin and to passenger ear.
2. Powertrain noise to underbody area to cabin and to passenger ear.
3. Engine and driveline attachment vibrations to underbody area to cabin and to passenger ear
4. Suspension attachment vibrations to underbody area to cabin and to passenger ear.
5. Tyre patch to underbody area to cabin and to passenger ear
6. Tyre patch to vehicle exterior area to cabin and to passenger ear
7. Exhaust to underbody area to cabin and to passenger ear
8. Exhaust to vehicle exterior area to cabin and to passenger ear

Sources

Measurement of accelerations are made on engine block path, driveline attachment and exhaust attachments. Sound pressure level measurements are also conducted in the engine compartment, tyre patch and exhaust tailpipe orifice, for below mentioned driving conditions. As statistical energy analysis method is used, phase information between sources is not required.

1. 3rd gear WOT 1000-4000 RPM in 1000 RPM bands
2. 100 kmph constant speed in 5th gear

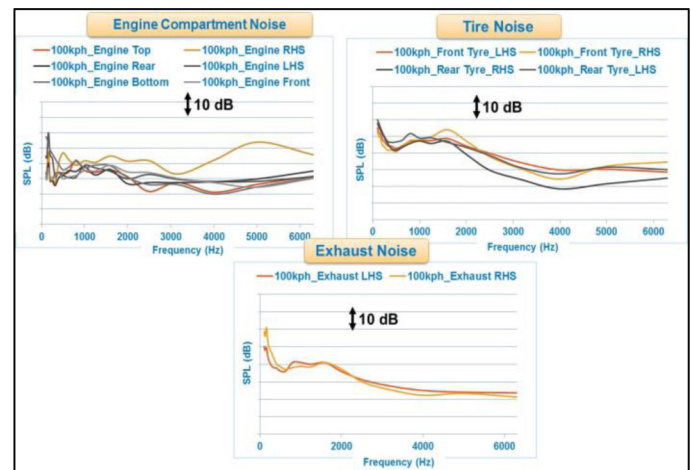


Figure 2. Excitations measurement (noise) for constant speed test case

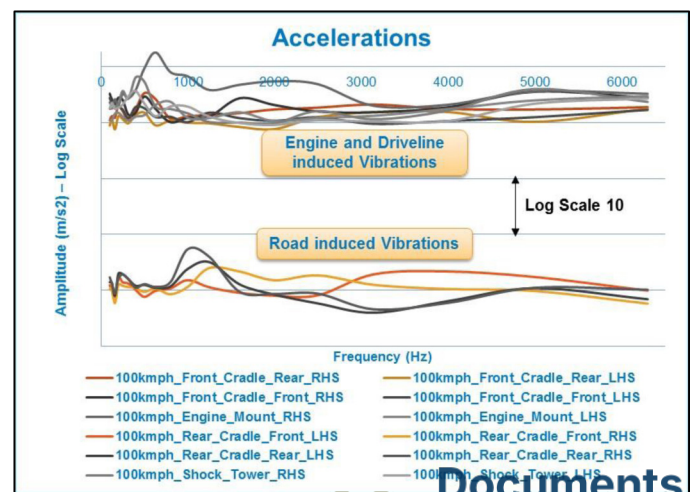


Figure 3. Excitations measurement (accelerations) for constant speed test Case

Different sources for a driving condition, constant speed 100 kmph are shown in figure 2 & figure 3.

PREDICTION THROUGH SEA AND VALIDATION

Vehicle level model for the SUV is built in SEA and measured test excitations are applied to the model for static and dynamic load cases. Predicted SEA results are then correlated with test results.

Vehicle SEA Model Build

To simulate above mentioned sources and predict cabin noise, a full vehicle model is built comprising of 900 panels, 150 beams and 200 cavities [5]. Suspension is modeled as beams. Bushings and corresponding body connections are modeled as isolators. Body is modeled using flat plates and singly curved shells [4]. Biot parameters (density, flow resistivity, porosity, tortuosity, viscous characteristic length, thermal characteristic length, loss factor, young's modulus, and poisson's ratio) for sound package layups are measured experimentally and the properties are used in SEA model. Laboratory based tests of noise reduction measurements are used for modelling and tuning door seals. Full vehicle SEA model is shown as in figure 4.

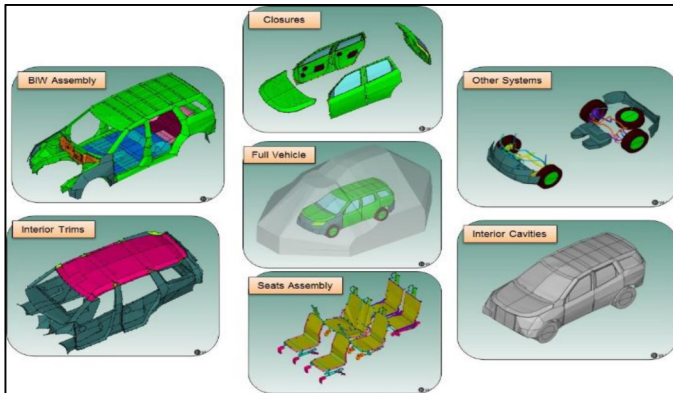


Figure 4. Full vehicle SEA model

Prediction and Validation for Static Load Cases

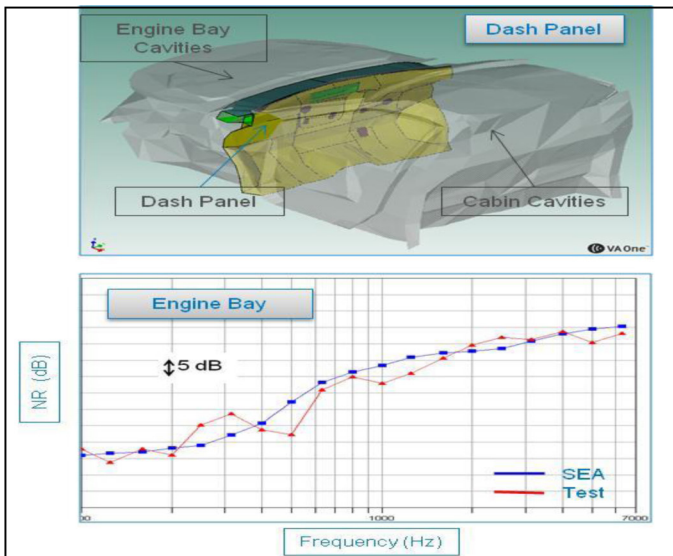


Figure 5. Noise reduction across dash

Static load cases included noise reduction measurements and simulations, across major panels. Noise reduction levels are measured across firewall, doors and wheel arches. Good agreement is seen in test and simulations data from 600Hz-6000 Hz, after model updation. Deviation in correlation is seen between 200 Hz-500 Hz ranges. It is on account of model validity from 300 Hz onwards and inability to capture right data for noise reduction using volume velocity sources in testing. Figures 5, 6 and 7 show the correlation of noise reduction across firewall, across doors and across wheel arches, respectively. Measured noise reduction across seals of all doors are used for tuning noise reduction across seals in SEA model.

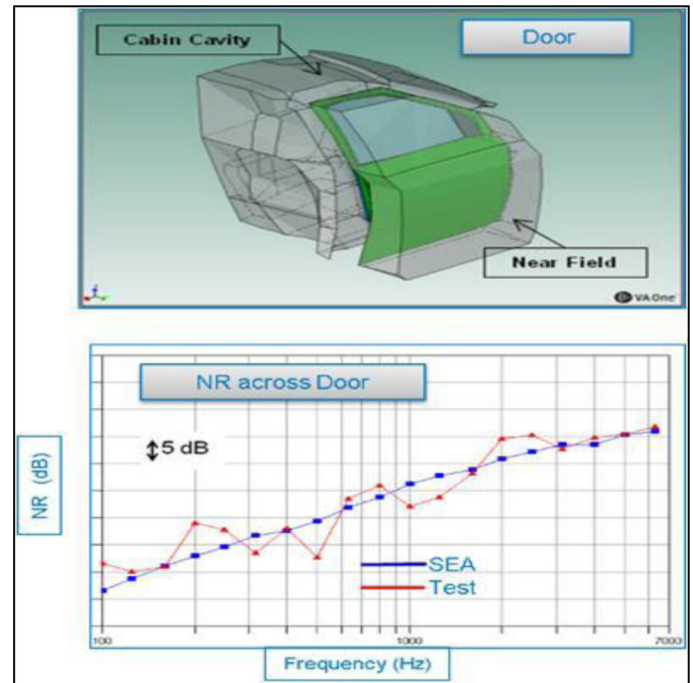


Figure 6. Noise reduction across doors

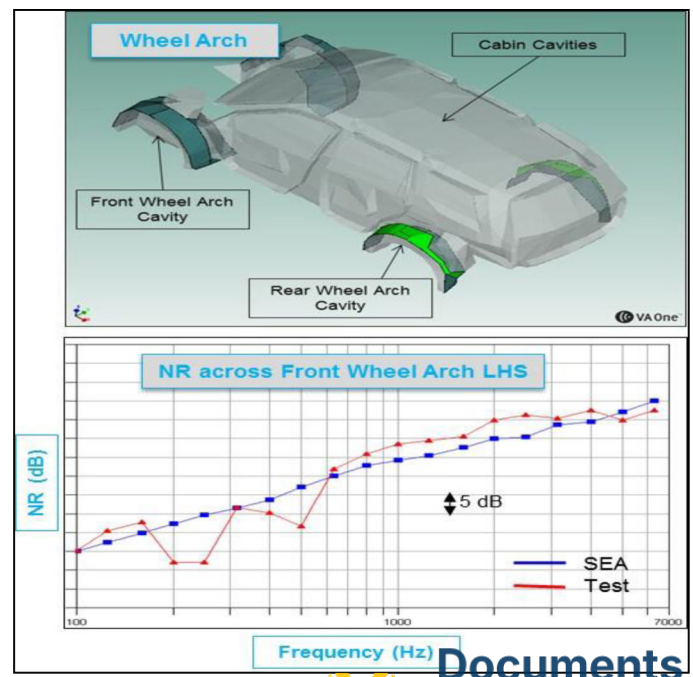


Figure 7. Noise reduction across wheel arch