

Lightweight Acoustic System Performance Target Setting Process

Qijun Zhang and Alan Parrett
General Motors Co.

Alexander Zopp
Adam Opel GmbH

ABSTRACT

In the vehicle development process, one important step is to set a component performance target from the vehicle level performance. Conventional barrier-decoupler dash mats and floor trim underlayment systems typically provide sound transmission loss (STL) with minimal absorption. Thus the performance of such components can be relatively easily specified as either STL or Insertion Loss.

Lightweight dissipative or multi-layered acoustic materials provide both STL and significant absorption. The net performance is a combination of two parameters instead of one. The target for such components needs to account for this combined effect, however different suppliers use unique formulations and manufacturing methods, so it is difficult and time consuming to judge one formulation against another.

In this paper, a unique process is presented to set a component target as a combined effect of STL and absorption. This process utilizes a Statistical Energy Analysis (SEA) vehicle level model to create a spreadsheet based Response Surface Model in MS Excel. The combined effect of the acoustic components can then be evaluated against a vehicle level target in spreadsheet without the need to input each supplier's submission into the vehicle level SEA model. This method greatly simplifies the specification process as well as allowing suppliers to quickly evaluate the impact of their parts on the vehicle level performance without the knowledge of the performance of any other vehicle content.

CITATION: Zhang, Q., Parrett, A. and Zopp, A., "Lightweight Acoustic System Performance Target Setting Process," *SAE Int. J. Passeng. Cars - Mech. Syst.* 6(2):2013, doi:10.4271/2013-01-1982.

INTRODUCTION

Traditional vehicle interior acoustic treatments for the dash and floor have utilized barrier-decoupler systems with a rubber-like barrier material covering either foam or fibrous decoupler. The main acoustic function of these constructions is to block the transmission of powertrain noise (dash) and road noise (floor system) into the interior of the vehicle. In general they provide limited acoustic absorption. The performance is relatively easily specified in terms of a Sound Transmission Loss (STL) or Sound Power Based Insertion Loss (PBIL) which is based on STL. In addition, the test methods used to evaluate STL have been standardized and the analysis of performance is a straight-forward process with currently available Statistical Energy Analysis (SEA)[1,2,3] and other acoustic analysis computer codes.

The continual desire for improved fuel economy and reduced mass has led to the development by acoustic suppliers of alternative light weight constructions for dash

and floor trim systems. There are a wide variety of systems in use such as dual impedance fibrous systems consisting of a dense fiber layer bonded on top of a lofted fiber layer [4], and a wide variety of multi layer systems consisting of decoupler, barrier (either lighter weight or thin film), and absorber systems. The acoustic performance of these light weight systems is dependent on both their STL and acoustic absorption. This performance is highly dependent on the construction, the materials used, and the manufacturing process involved. This in turn is very dependent on supplier's manufacturing, design and analysis/test capabilities.

A challenge for the OEM is the ability to determine vehicle performance from different (unique) combinations of STL and absorption from different suppliers. Further, a single supplier may offer different materials/combinations of performance based on the tunability of their materials and process.

To illustrate the challenge, consider a component specification (such as for an inner dash mat or floor trim system) with a given overall STL and absorption level deemed by the OEM as capable of meeting vehicle targets. The choice of submissions from various suppliers is made difficult because of their individual component's mix of performance.

With two technical targets, to judge whether one system (A) is better or worse than another (B) relative to both performances, the following scenarios will result:

1. AbsorptionA > AbsorptionB and STLA > STLB
2. AbsorptionA > AbsorptionB and STLA < STLB
3. AbsorptionA < AbsorptionB and STLA > STLB

In scenario 1), it is obvious that material A is better.

In the scenarios 2 and 3 it is hard to determine which is better, and this is the case most often encountered.

For the case 2 or 3, it is necessary to run a SEA model with both STL and absorption performance to determine the overall in-vehicle performance, which relates ultimately to what a customer perceives.

Since the OEM owns the vehicle level performance as well as the vehicle SEA model, the approach above will require the OEM's SEA engineer to be involved in the process to evaluate the performance of various acoustic systems from different suppliers. The time and resources available to perform such evaluations is limited in the context of program timing and part sourcing, so another approach was developed.

The new approach consists of a material performance evaluation tool which allows a supplier to perform iterations and optimization on their own without the involvement of the OEM. This greatly streamlines and speeds up the process.

The Response Surface Model (RSM) method is used to build this model. In this case the RSM is a model of the results of an SEA model in response to variations in the input parameters (STL/PBIL and Absorption of the floor trim and dash systems). In this paper, Microsoft Excel is used as the platform for the RSM with an easy to use quick tool.

RESPONSE SURFACE MODEL (RSM)

A performance based SEA Program Model has all the noise paths and sources for road noise and powertrain noise analysis defined. Subsystem performance is specified in terms of STL and absorption. The components in focus here are only the floor trim system and dash mat system. To evaluate the in-vehicle performance of different floor trim and dash mat systems with the SEA model, it is relatively simple to apply those component performance data to the model and solve for the results.

To assess the component performance without the usage of the SEA model, an intermediate model is required. This model, unlike the SEA model, has the variables to represent only the component performance of interest, which are the floor trim and dash mat system.

Variables and Limits

Each independent component has a variable to represent either its STL performance or absorption performance. Since in the SEA formulation every frequency band calculation is independent, the same variable can be used for all the bands with different performance ranges. For this reason, the variable will be normalized as below,

$$STL = STL_{Mean} + (STL_{Up} - STL_{Low}) * x_{STL} \div 2 \quad (1)$$

where x_{STL} is the normalized STL variable, with values in between ± 1.0 , $STL_{Mean/Low/Up}$ are the STL performance mean value, Lower limit and Upper limit.

The same methodology applies to the absorption variable.

The RSM will be valid with only the defined variables having values in a certain range, which is predefined as the upper/lower limits in the RSM creation process.

Due to the variety of noise control material solutions anticipated, the upper and lower limits used in the model creation need to be sufficient to span the range of possible values in this RSM.

X² DOE Matrix

Based on the number of variables and upper/lower limits for each one, a DOE (Design of Experiment) matrix is generated for a given number of total runs.

To improve the RSM quality, a x^2 orthogonal array [5] is used as the DOE matrix. The x^2 orthogonal array has a uniform sampling distribution as shown in Figure 1 between any two variables. This will ensure sufficient sampling points for each variable and also a uniform sampling across the entire multi-dimension space.

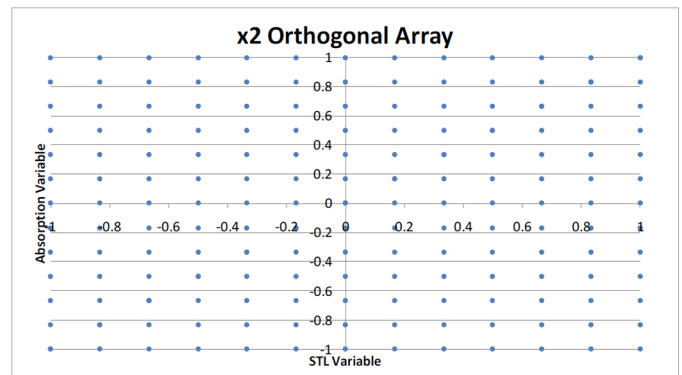


Figure 1. x^2 Orthogonal Array with two normalized variables

Figure 1 shows two variables normalized for STL and Absorption for a frequency band. The normalization can be done using upper/lower limit of each variable as in eq. (1). The upper and lower limits can be a function of frequency but the variable will always have the range of $(-1.0, 1.0)$.

The x^2 orthogonal array has the size of $(n-1)^2 \times n$, where n is the number of variables (columns). Either the whole range