

Investigation of Tire-Road Noise with Respect to Road Induced Wheel Forces and Radiated Airborne Noise

Gregor Koners and Ralf Lehmann
Daimler AG

ABSTRACT

Low interior noise levels in combination with a comfortable sound is an important task for passenger cars. Due to the reduction of many noise sources over the last decades, nowadays tire-road noise has become one of the dominant sources for the interior noise. Especially for manufactures of luxury cars, the reduction of tire-road noise is a big challenge and therefore a central part of NVH development.

The knowledge of the noise transmission behavior based on the characteristics of the relevant sources is a fundamental of a modern NVH - development process. For tire-road noise the source characteristics can be described by wheel forces and radiated airborne noise. In combination with the related vehicle transfer functions it is possible to describe the noise transmission behavior in detail.

A method for estimating wheel forces and radiated airborne noise is presented. The method is based on TPA (= Transfer Path Analysis) via matrix inversion and involves the measurement of the vehicle transfer functions. It can be applied to analyse the interior noise under different driving conditions such as driving on smooth or rough roads. TPA is used to estimate the wheel forces and radiated airborne noise, as well as the interior noise level. In this study, good agreement was found between TPA-calculations and measurements of wheel forces (Kistler Wheel Force Sensor) and interior noise.

Finally, advantages and disadvantages of the wheel TPA method are discussed, and future research topics are identified.

CITATION: Koners, G. and Lehmann, R., "Investigation of Tire-Road Noise with Respect to Road Induced Wheel Forces and Radiated Airborne Noise," *SAE Int. J. Passeng. Cars - Mech. Syst.* 7(3):2014, doi:10.4271/2014-01-2075.

INTRODUCTION

The continuous optimization of passenger cars over the last years led to a powerful reduction of the interior noise. Tire-road noise has therefore become an important topic in NVH research.

Depending on velocity, road surface condition, body, suspension and wheel, different tire-road noise phenomena can take place. A short overview is given in [Figure 1](#). Typical tire-road noise phenomena are listed next to the relevant frequency range.

One fundamental goal in NVH development is noise source identification (i.e. powertrain component, rear differential, driveline, tire-road, et al.). With the knowledge of these sources the next step is the identification of the transmission behavior behind the problem. This can be achieved using an analytical tool known as Transfer Path Analysis (TPA). TPA is typically used to characterize the single noise path contributions to the total interior noise.

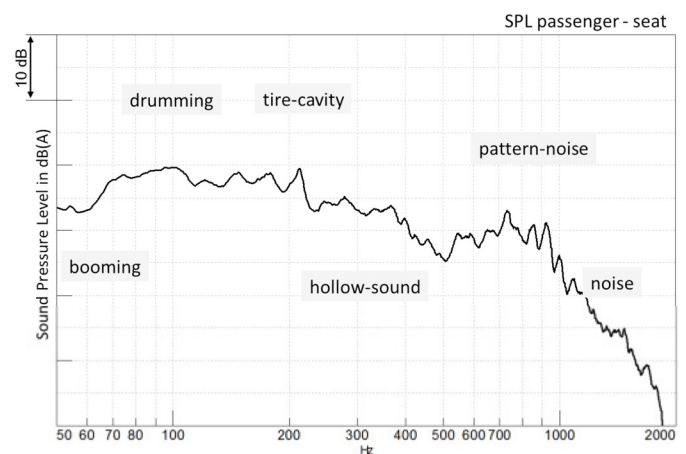


Figure 1. typical tire-road noise phenomena and the corresponding frequency range

For the case of tire-road noise, the interior noise is split up into structure-borne and airborne noise. [Figure 2](#) illustrates this graphically.

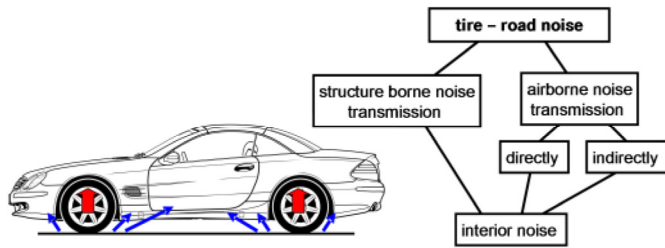


Figure 2. general noise transmission behavior

Earlier studies [1] show that structure-borne noise transmission is confined to frequencies below 600 Hz, and airborne noise transmission occurs at frequencies above 400 Hz. (i.e. tire-cavity: here both structure-borne and airborne noise is possible).

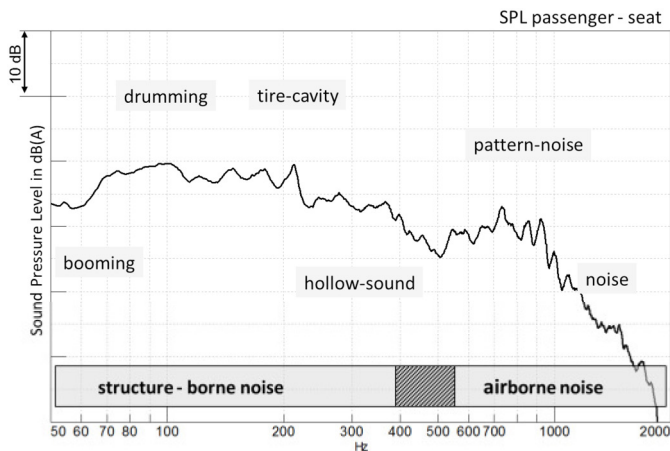


Figure 3. structure-borne and airborne noise transmission with typical tire-road noise phenomena and its corresponding frequency range

Referring to Figure 1, this means that booming noise, drumming, tire-cavity and hollow sound are mainly dominated by structure-borne noise; and, airborne noise is responsible for pattern-noise and noise in frequencies above 1000 Hz.

To reduce the effort required for tire-road noise investigations, a coherence analysis may be applied as a preliminary study. As a result of this study it is possible to address transmission behavior a little bit more in detail [2]. First, the analysis shows whether more structure-borne or airborne noise is behind the problem of interest, and based on this information, it is possible to determine if transmission takes place at the front axle, at the rear axle or both. Coherence analysis is a valuable heuristic tool for initial road noise investigations. It is often used for global assessment of noise transmission problem zones. However, since the results of a coherence analysis are rather qualitative in nature, supplemental tools such as TPA or operational modal analysis (OMA) are used to gain a deeper, quantitative understanding of noise phenomena.

The first step of a full-blown TPA measurement involves performing extensive impact measurements on the "trim-body", that is, the car without its powertrain and suspension. Such a measurement will require weeks of painstaking measurements. A less extensive "wheel-TPA" is an interesting alternative. For a

given road induced wheel excitation, the wheel-TPA can be used to assess the source and transmission characteristics for structure-borne and airborne noise. Physical parameters such as wheel forces, radiated airborne noise, and all necessary transfer functions can be estimated and compared. Also it is possible to use the estimated forces as a load case for finite element calculations.

ESTIMATION OF WHEEL FORCES

In order to identify the structure-borne noise transmission more in detail, a transfer path analysis TPA instead of a coherence analysis is applied. The process is very similar to classical TPA via matrix inversion method. Instead of mount forces (i.e. suspension links or powertrain mounts) now the wheel forces are estimated. Together with the related acoustic transfer functions (P/F) it's possible to predict all single noise contributions based on structure-borne noise transmission. The measured interior Noise P_{IN} can be written as the sum of structure-borne noise P_{SN} and airborne noise P_{AN} .

$$P_{IN} = P_{SN} + P_{AN} \quad (1)$$

The partial structure-borne sound pressure levels P_{SNI} are calculated by multiplication of the acoustic-mechanical transfer functions ATF's P_{SNI}/f_i of each single transfer path i with the related operational wheel force F_i . Now, the interior noise P_{SN} due to structure-borne noise transmission, is given by the summation of these products

$$P_{SN} = \sum_{i=1}^m P_{SNI} / f_i * F_i \quad (2)$$

The operational wheel forces F_i for each transfer path are computed using a classical pseudo invers matrix method [3; 4].

$$\{F\} = [H_{af}]^{-1} \cdot \{a\} \quad (3)$$

In equation (3), $[H_{af}]$ is the force-acceleration FRF-matrix between paths and indicators; and $\{a\}$ contains the operational accelerations measured at all indicator points.

The calculation of the forces F_i requires correlated accelerations. This is necessary, because a fixed phase relationship between all vibrations is assumed. Therefore, for the case of road noise analysis, a principal component analysis (PCA) has to be applied [5].

For a limited number of paths, the amount of effort required to conduct a TPA is minimal. Under the assumption that the dynamic influence from the suspension is negligible, TPA calculations would then yield information about the source characteristics of wheels and road surfaces. TPA