Road Noise Analysis Using A Binaural Time Domain Approach

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Introduction

In modern passenger cars powertrain noise has been continously reduced. Thus other noise sources, especially road and tire induced noise, become increasingly important for the overall sound quality.

Road noise is generated by different mechanisms: Tire rolling noise on plain or coarse road and noise from single bumbs. Noise sources can be airborne (sound radiated directly from the tire) and structure-borne (vibration transmitted through the car body and radiated in the interior).

In order to understand generation and transfer of road noise and to improve sound quality, several analysis methods have been developed, including transfer path analysis (TPA) and multiple coherence. While the TPA approach requires the measurement of individual transfer functions, coherence analysis does not. TPA delivers more detailed information on the transfer of noise through the vehicle, but the latter method offers a much faster insight in the origins of noise patterns. A combination of both methods yields large benefits for road noise analysis.

Multiple Coherence Analysis

Each wheel of a rolling car makes up one airborne and one structure-borne noise source being mostly incoherent with respect to the other wheels' sources, and even with one wheel airborne and structure-borne source being incoherent [1]. Thus the resulting interior noise is composed from a number of partly incoherent noise shares. A frequency-dependent level of coherence between the interior noise and one or more reference input(s) can be calculated, if the different source signals are known. This can be achieved by recording the interior noise with a microphone and measuring each tires' source signals using accelerometers and microphones, respectively.

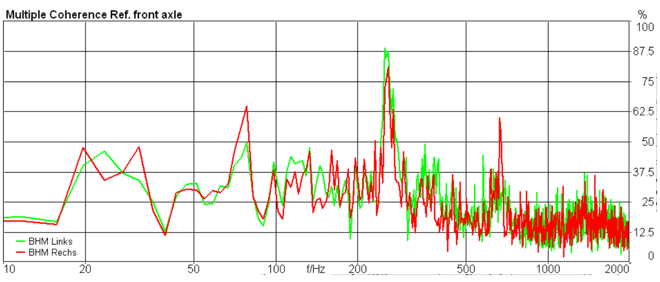

Figure 1: Multiple coherence spectrum based on triaxial vibration measurements at the front wheels

The resulting coherence spectra show the percentage of interior SPL originating from specific sources. This information can be used to identify origins of unwanted interior noise components. A typical coherence spectrum is shown in Figure 1, it represents the noise portion originating from front axle vibration inputs based on a binaural recording.

As indicated above, the different road noise sources are mostly incoherent, i.e. at some frequencies coherent vibration can be observed. This can be due to coupling through the drive line of the front axle, for example. The sum of multiple coherence functions will then exceed 100%. In these cases, the number of assumed independent sources has to be reduced by forming larger groups of reference signals.

Coherence-Based Auralization

Using a simple algorithm FIR filters can be created from coherence spectra. By then filtering the recorded interior noise, the sound contribution is generated that originates from the sources chosen as reference inputs. In case of using an artificial head for recording, a very realistic reproduction is achieved.

For the following examples, reference signals have been picked up using triaxial accelerometers on each wheel base and two microphones (one in the front and one behind) at each tire. In general, measurements should be done on the road and not on a roller dynamometer, as the latter causes an unrealistic interior noise dominated by the harmonics of the roller rotation.

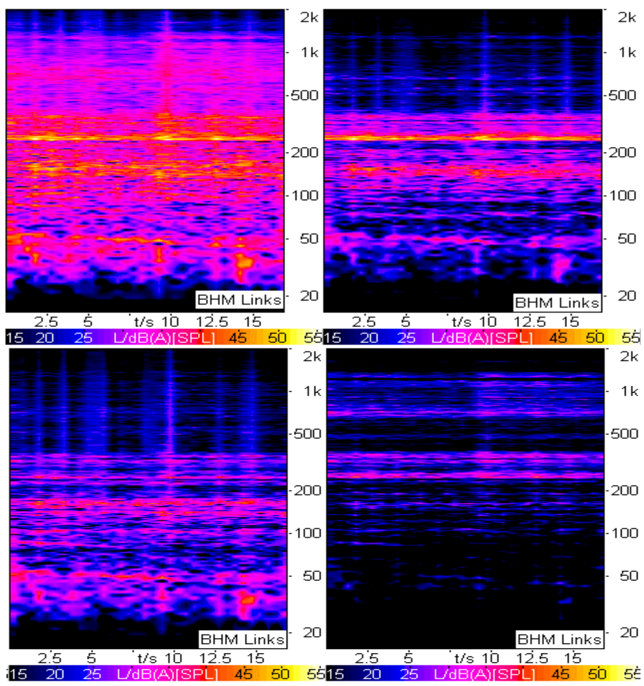

Figure 2: Road noise spectrograms: interior noise recording (top left), front axle structure-borne contribution (top right), rear axle structure-borne contribution (bottom left), airborne sound of all wheels (bottom right)

After the recording, various filters can be generated based on single or grouped reference sensors and one can listen to sound contributions from the front or rear axle, from single wheels or even distinguish between airborne and structure-borne sources. No transfer functions have to be measured and thus a significant amount of time is saved compared to a TPA based noise simulation. Figure 2 shows example spectrograms of a road noise recording (done at 70 km/h on coarse road, engine running at idle) and filtered noise contributions.

Transfer Path Analysis

Binaural Transfer Path Analysis and Synthesis (BTPA and BTPS) techniques have been developed for the prediction of sound quality in vehicles, not only in terms of numbers and graphs, but also for binaural auralization. The results can be used to create an accurate model for path-related noise heard anywhere inside the vehicle, thus yielding possibilities for troubleshooting and sound design. Each individual path or combination of paths can be listened to independently, in order to assess their respective impact on the overall sound quality. Paths can be modified to simulate countermeasures and their effect on the interior noise [2].

While the same sources as for coherence analysis are assumed, transfer paths consist of transfer functions for airborne damping (p/p), vibration damping (a/a), apparent mass (F/a) and vibroacoustic sensitivity (p/F). Figure 3 shows a schematic view of structure-borne noise transfer paths for one wheel. Each path is measured and analyzed in three directions (x,y,z).

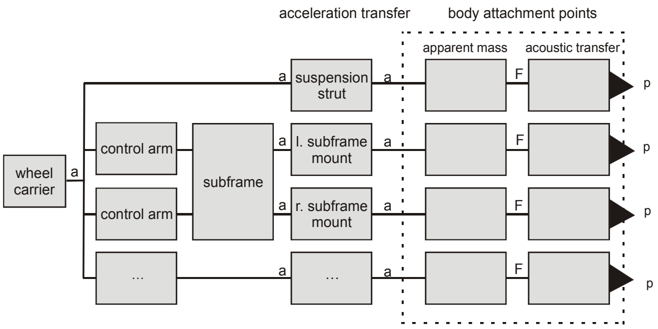

Figure 3: Structure-borne road noise paths and transfer functions (simplified example)

Of course, cross-coupling of transfer paths has to be considered. Regarding the different wheel sources, this can be done by coherence considerations and corresponding FIR filtering. Otherwise crosstalk matrices have to be measured or sub-systems have to be physically decoupled.

As an example, road noise transfer of a front-wheel driven car has been simulated based on the front suspension body attachment points. Including the wheel microphones for airborne noise, a total of 52 channels has been used. In Figure 4 the simulation results are shown next to the original recording. For further verification, the simulated front axle contribution has been added to the coherence filtered (as explained above) rear axle contribution. Thus the total tire and road induced noise is reproduced satisfactorily.

In all examples, when comparing recorded with simulated road noises, one has to remember that the recording contains also wind noise, which is of course not included in the simulations.

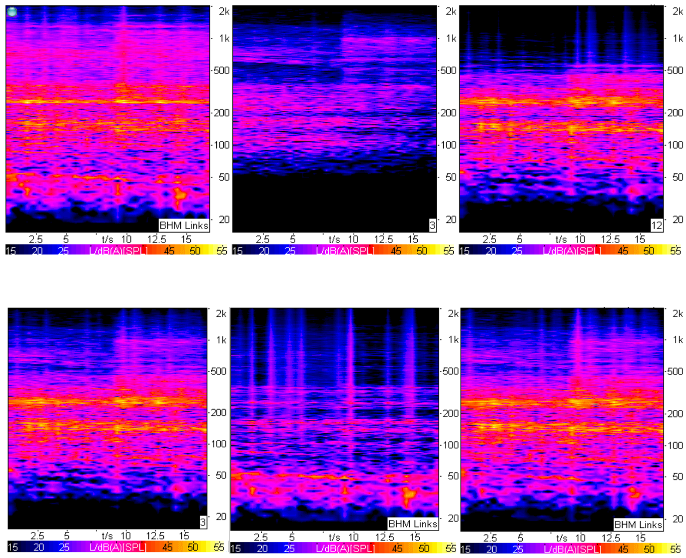

Figure 4: Road noise spectrograms: interior noise recording (top left), airborne contribution (top middle), front structure-borne contribution from BTPA (top right), front structure-borne plus airborne (bottom left), rear axle structure-borne from coherence filtering (bottom middle) and total sum (bottom right)

As stated above, the results shown in Figure 4 have been achieved using the TPA model starting at the front suspension body attachment points. Based on these investigations it is possible to focus further work on the most significant paths. The TPA may now be extended to single suspension elements like control arms and struts. The complete TPA model will enable the engineer to predict interior noise due to synthetic component modifications.

Summary

In order to better understand the sources and transfer of road and tire induced vehicle interior noise, a binaural time-domain approach has been presented. Coherence-based filtering provides a time-saving way for auralization of noise contributions. Binaural transfer path analysis and simulation allows for detailed insight into the noise paths and the transfer behaviour of suspension elements along with the possibility to generate listenable files. When coherence analysis is done at the beginning, transfer path analysis can be focused on subsystems that are contributing most to the interior noise. As both methods work in the time domain, all analyses can be accompanied by listening, thus the identification and characterization of noise patterns is greatly simplified.

References

[1] A. Crewe, D. Bogema, R. Williams, M. Balaam, M. Allman-Ward: Sound Decomposition – A Key to Improved Sound Simulation. SAE 2003-01-1423, 2003

[2] K. Genuit, J. Poggenburg: The design of vehicle interior noise using binaural transfer path analysis. SAE´99, 1999