Simulated Pass-By in Small Rooms Using Noise Synthesis Technology

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Introduction

Pass-by measurements are a standard test procedure for new vehicles. According to ISO 362 [1] this test is performed on a test track with a single microphone at a distance of d=7.5 m on both sides of the track. The vehicle passes the test successfully if the maximum SPL (dB(A)) is within the legal restrictions regardless of the sound quality. Since there are only few test tracks available and the measurements depend on the environmental conditions, an indoor test procedure has been developed [2]. Thereby, the vehicle is placed on a chassis dynamometer. The signal corresponding to the ISO 362 measurement is generated by switching between the signals of a microphone array at 7.5 m distance and applying filtering and smoothing algorithms. Furthermore, it is possible to calculate a binaural signal corresponding to an artificial head recording. Then, psychoacoustic analyses as well as jury evaluation tests could be performed.

There are only few chassis dynamometers which are large enough to fulfil the requirements of ISO 362 (area >= 15 x 30 m). Therefore, the next step is to develop a procedure that works almost independently of the room size. Within the European research project SVEN (**S**ound Quality of **V**ehicle **E**xterior **N**oise) [3] a procedure has been developed which allows synthesising a virtual microphone signal measured at an arbitrary far-field position. The procedure is based on near-field measurements at the dominant noise sources of the vehicle and on airborne transfer functions between these sources and the far-field. Apart from the generation of a standard pass-by signal, this procedure allows the investigation/ranking of the contribution of single sources to the exterior noise as well as the virtual replacement of noise radiating vehicle components. This paper presents modifications and improvements of the standard SVEN procedure.

Noise Synthesis

Noise synthesis is based on the idea that the overall sound/noise emitted by the vehicle is considered to be the sum of a finite number of dominant noise sources (e.g. wheels, engine, exhaust etc.). Similar to the transfer path synthesis used to simulate the interior noise, the complete transfer path from each individual source to the observer at the road track has to be determined. The transfer path between the source and the observer is called **S**ource **R**elated **T**ransfer **F**unction (SRTF). It contains the radiation pattern/directivity of the source and the airborne transfer path to the observer in the far-field. There are two key problems to be solved in order to get a correct exterior noise synthesis: Firstly, one has to find the right positions for the source microphones for capturing source directivity and reducing crosstalk and secondly, the measurement of the SRTF.

Direct approach

Within the SVEN project a direct approach for the measurement of the SRTF was applied. Here, small, but powerful loudspeakers are placed at the microphone positions in the very close near-field of the sound sources. A microphone is placed at each far-field observer position of interest. The airborne transfer functions from every source to every observer position are measured by activating one loudspeaker at a time. The major drawback of this approach is the need to place the loudspeakers in the near-field. The loudspeaker has to be loud enough to ensure a sufficient SNR, but must be small enough to be placed exactly at the microphone positions. Especially in the engine compartment the space and therefore the possibility to place loudspeakers is very limited. Furthermore, the loudspeakers should have the radiation pattern of a monopole.

Reciprocal approach

To avoid the drawbacks of the loudspeakers a reciprocal approach to measure the SRTF has been developed. Transfer paths are measured between microphones placed near the sources and a monopole sound source at the far-field observer position. The main advantage of this approach is that the same microphones being used later on for the source measurements can be used for the measurement of the transfer function without the need to change the instrumentation of the vehicle. The monopole source has been developed at the Institute of Technical Acoustics (ITA) of the Technical University Aachen (figure 1).

Figure 1 Monopole sound source. Mid-frequency dodecahedron (d = 27 cm) mounted on subwoofer (left) and high- frequency dodecahedron (right, d = 16 cm)

It contains a subwoofer and two dodecahedrons, optimized for different frequency ranges which are mounted on the subwoofer. The whole system has more or less the characteristics of a monopole for frequencies between 20 – 4 kHz. The figures (2) and (3) show the result of a basic reciprocity test performed by interchanging the mid-frequency dodecahedron (range 200 – 1200 Hz) and microphone positions in a given reverberating environment. The differences between curves of one colour are caused by turning the dodecahedron and therefore represent the deviation from a perfect monopole.

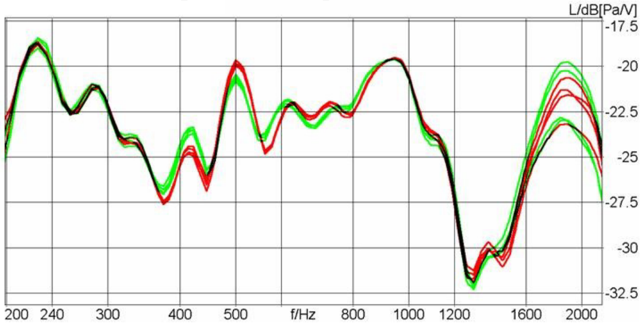

Figure 2 Airborne transfer functions measured with the mid-frequency source directly (green curves) and reciprocally (red curves) in a reverberating environment

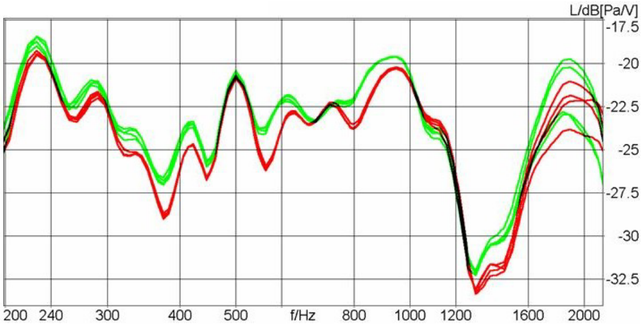

Figure 3 Airborne transfer functions measured with the mid-frequency source directly (green curves) and reciprocally with a 2 cm positioning error (red curves)

In the frequency range of 200 Hz – 1200 Hz the reciprocity assumption is fulfilled within 1 dB for small positioning errors (figure 2). Positioning errors exceeding 2 cm lead up to 2 dB deviation (figure 3). Above 1200 Hz deviations up to 3 dB are caused by the increasing directivity of the mid-frequency-dodecahedron.

Synthesis

Once the SRTF are measured for the whole range of interesting far-field positions, near-field noise radiated by the vehicle can be measured on the road or on a chassis dynamometer. The near-field measurements are filtered with corresponding SRTFs. The resulting sound signals are summed up to get the expected far-field signals. This direct approach may fail if the source microphones are not placed at the optimum positions capturing the source directivity or if there is extensive crosstalk between close-by microphones. A straightforward approach to overcome these problems is to measure correction functions for single sources or at least groups of sources. Using a four-wheel chassis dynamometer it is possible to measure correction functions for the front wheels, the rear wheels and the power train without any additional instrumentation. In order to calculate for example the front-wheels correction function the chassis dynamometer drives the front-axis without running engine. Then the near-field sounds at the front wheels as well as the sounds at far-field positions with already known transfer functions are simultaneously measured. The difference between the synthesized and the measured far-field sound signal will be almost independent of the far-field position or the driving conditions and can be used as correction function for the real chassis dynamometer measurements.

Figure 4 shows the left channel of a binaural pass-by signal calculated using a real far-field microphone array measurement, whereas figure 5 shows the corresponding signal calculated using synthesized near-field component measurements.

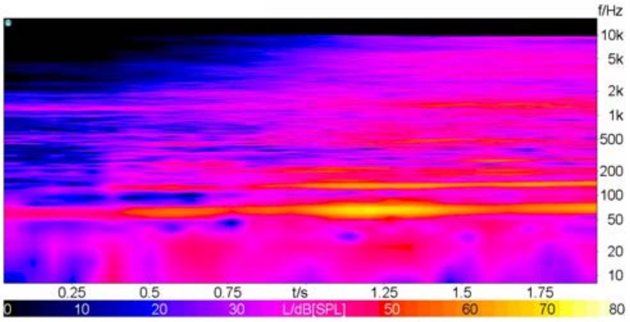

Figure 4 Simulated pass-by (left ear) calculated using far-field array measurement

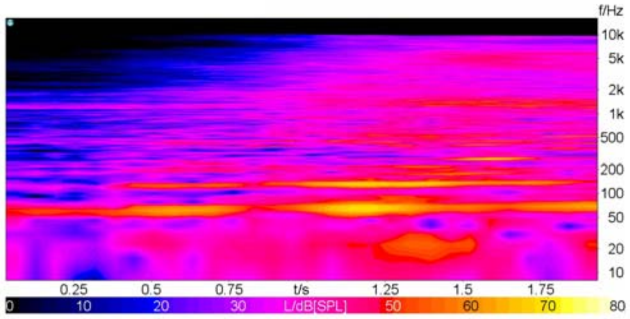

Figure 5 Simulated pass-by (left ear) calculated using near-field component measurement

Conclusion and outlook

The above described pass-by software is a powerful tool to simulate monaural or binaural recordings of pass-by noise using a chassis dynamometer and a microphone array. Exterior noise synthesis as developed during the SVEN project is the first step in overcoming the need for a large chassis dynamometer and creates numerous new applications in the field of sound design and component testing. The reciprocal measurement of the source related transfer function (SRTF) presented in this paper improves the method significantly by allowing almost free positioning of the source sensors as well as a reduced time needed for vehicle instrumentation and measurement. The described correction functions are a first straightforward approach to eliminate the errors caused by source crosstalk and directivity. The next step will be to measure and integrate source directivity models in the synthesis algorithm.

References

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[3] R. Sottek, W. Krebber, K. Genuit: Road traffic noise simulation in urban streets, InterNoise 2002, paper N188