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Experimental Pass-By Noise Source Analysis

Approach based on measured transfer functions

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1 Introduction

The work described in this report is part of Task D 2.2 (user friendly and fast methods). Target of this work is the sound source identification during vehicle pass-by based on experimental approaches. Basic investigations have already started in an earlier European project (VISPeR).

The principal idea was to combine source related noise measured close to sound emitting surfaces with (measured or calculated) transfer functions. It was found that a minimum of two microphones should be used for every source to avoid local resonance effects. In the transfer function measurements two approaches were compared. The results showed that a measurement with sound source outside the vehicle yielded much better results. So only this approach was further applied.

Within the first year of the Silence project the measurement procedure was refined and a software for the handling and analysis of the huge amount of measurement data was developed.

2 Description of Analysis Procedure

The analysis of the contribution of different sound sources to the total pass-by level is composed of two measurement steps preceding the actual analysis. In the first step the sound radiation of each component has to be determined. In the second step the transfer functions between those components and the “moving” pass-by microphones have to be measured.

2.1 Noise Radiation Measurement

The noise radiation of the individual components is determined by microphones located close to the respective noise radiation surface. The noise is recorded during a full load acceleration in 2nd and 3rd gear. This measurement should not just cover the actual engine speed range of the real pass-by test but the whole engine speed range. So it will later in the analysis be possible to simulate the effect of modified gear ratios.

In the near field noise analysis each component should be at least covered by two microphones to avoid measurement errors from the influence of local resonances in the engine compartment. For large and presumable important components like engine block, oilpan or gearbox even more microphones are required to cover the different sides of the noise source. Potential noise sources to be covered in such an analysis are typically engine block (different sides), cylinder head, oilpan (different sides), front accessory drive, gearbox, intake orifice, intake system (air cleaner housing), exhaust mufflers, exhaust orifice, tires, etc. Altogether 20 or more source microphone have to be installed into the vehicle.

2.2 Transfer Function Measurement

The transfer function measurement is the most lavish part. For this analysis the inverse transfer function method is applied. A noise source is positioned outside the vehicle (at pass-by microphone position) and the transfer functions to the source microphones determined. This procedure requires a large anechoic room because the pass-by microphone does not only need to be 7.5 m beside the vehicle longitudinal axis but must also cover the range from

10 m in front of the vehicle to 10 m behind. So the sound source has to be positioned at numerous positions (recommended step 1 m) left and right side of the vehicle to cover the changing transfer function during the pass-by test.

To perform this analysis in a smaller anechoic room it is theoretically possible to do the transfer function measurement with the sound source at a smaller distance from the vehicle centre line and compensate the transfer function level by a correction function. The problem of such procedure is the varying distance in between source microphones (in vehicle) and sound source. The correct compensation for sources in the front area (engine compartment) and in the rear area (exhaust system) is difficult. An average compensation leads to a weighting shift of those components over the pass-by travel distance.

Another possibility for the transfer function measurement is to do this outside. Here a quiet surrounding and a powerful sound source is required. Else the quality of the measured transfer function will not be sufficient due to disturbing noise influences.

2.3 Data Evaluation Procedure

The challenge of this task is the handling of the huge amount of data. If the measurement was performed for 20 source microphones and 25 noise source positions on each side of the vehicle (1 m step, vehicle length ± 10 m, left and right side) overall 1000 transfer functions have to be assigned correctly.

Although each source microphone could be treated separately AVL recommends to first average excitation data (noise spectra measured during full load acceleration) and transfer functions for each source. In the case of expected directivity of the noise radiation of a single source the different noise radiating surfaces have to be treated separately (e.g. engine block left and right side, at least 2 microphones each side required).

The next step is to create the correct vehicle position – engine speed relation for both gears. This data is normally taken from a real pass-by test.

Afterwards the noise contribution of each component to the overall pass-by noise is calculated. For each vehicle position (1 m step according to the measurement of transfer functions) the noise spectrum of the source (selected by engine speed) has to be multiplied by its sound radiating surface (size) and by the respective transfer functions (left and right, selected by source and position). As a check of measurement accuracy the total noise level summed up from all single components should be close to the real pass-by level of the vehicle.

3 Work Performed within the First Year of Silence

3.1 Improvement of Hardware

In the original development the transfer functions were measured between two microphones. One microphone was positioned outside the vehicle (pass-by microphone position) and the other one near the potential vehicle noise source. A loudspeaker radiating white noise was positioned behind the pass-by microphone.

The loudspeaker was always directed towards the vehicle but the risk of different radiation characteristics towards the front and the rear of the vehicle remained. A single loudspeaker must have a certain size to produce enough sound power in the low frequency range. But such a loudspeaker is no uniform radiator for high frequencies. On the other hand a two way speaker system bears the risk of phase problems in the transition range from one speaker to the other.

An additional source of potential errors is the distance between loudspeaker and first microphone. But this error is only around 0.1 dB when the distance is one meter (± 0.2 m). And if the microphone is fixed with the loudspeaker on a common tripod at a fixed distance potential distance variation is eliminated.

So the loudspeaker / microphone combination was replaced by a special sound source (Omnisource B&K 4295). This sound source uses a single loudspeaker inside a rigid housing. The noise created can only exit through a relatively small hole creating a point source characteristic over a wide frequency range. The risk of directivity errors is eliminated but through the spherical radiation the radiated sound power must be higher to achieve a good signal to noise ratio during the transfer function measurements (especially for “hidden” microphones).

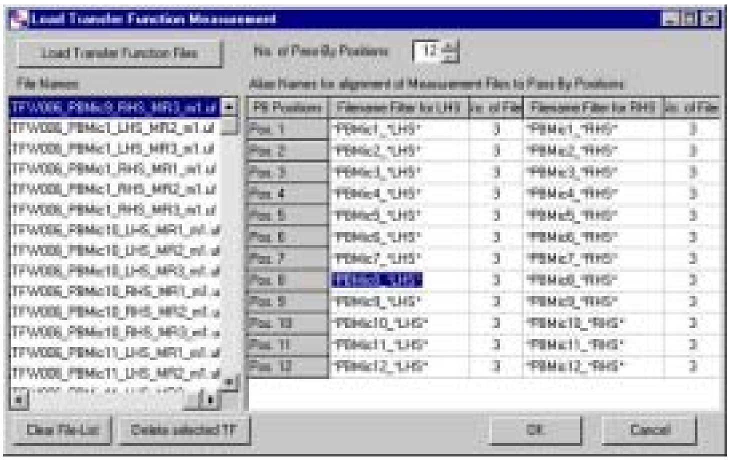
Also the microphone near the noise source was omitted and the electric power used to drive the sound source is measured instead. A reference frequency response function in between electric signal and emitted sound power was determined in an anechoic room to correct the measured transfer functions.

To improve the critical signal to noise ratio the white noise excitation signal was replaced by a swept sine.

3.2 Development of Analysis Software

Within the Silence project AVL was also working on the improvement of the data evaluation process described in Chapter 2. A specific software called PCA (Pass-by Contribution Analysis) was written to support the data handling. Still all the transfer functions have to be exported from the measuring system to the analysis software. But the selection of the appropriate transfer functions (depending on vehicle position) and the correct switching to the next one is now done automatically reducing the risk of operator errors (Picture 1).

Picture 1: Import of measured transfer functions



No. of Pass By Positions: 12

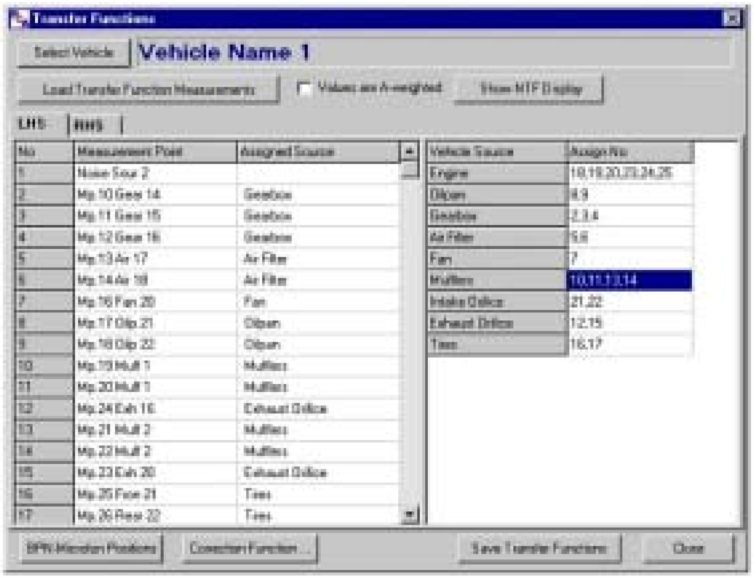
Alias Names for alignment of Measurement Files to Pass By Positions

PB Positions	Filename Filter for LHS	o. of File	Filename Filter for RHS	o. of File
Pos. 1	*PBMic1_*LHS*	3	*PBMic1_*RHS*	3
Pos. 2	*PBMic2_*LHS*	3	*PBMic2_*RHS*	3
Pos. 3	*PBMic3_*LHS*	3	*PBMic3_*RHS*	3
Pos. 4	*PBMic4_*LHS*	3	*PBMic4_*RHS*	3
Pos. 5	*PBMic5_*LHS*	3	*PBMic5_*RHS*	3
Pos. 6	*PBMic6_*LHS*	3	*PBMic6_*RHS*	3
Pos. 7	*PBMic7_*LHS*	3	*PBMic7_*RHS*	3
Pos. 8	[illegible]	3	*PBMic8_*RHS*	3
Pos. 9	*PBMic9_*LHS*	3	*PBMic9_*RHS*	3
Pos. 10	*PBMic10_*LHS*	3	*PBMic10_*RHS*	3
Pos. 11	*PBMic11_*LHS*	3	*PBMic11_*RHS*	3
Pos. 12	*PBMic12_*LHS*	3	*PBMic12_*RHS*	3

The near field microphones are then assigned to the different sources for the transfer functions (Picture 2) as well as for the noise measurement data recorded during full load acceleration (Picture 3).

To improve the quality of the results the measured transfer functions are interpolated for a vehicle travel step of 0.25 m. Through this measure the curves showing noise level versus vehicle position become more smoothed. If the transfer function switching distance is too large the change in the transfer function could be seen as a step in the calculated level.

Picture 2: Assigning transfer functions to different sources

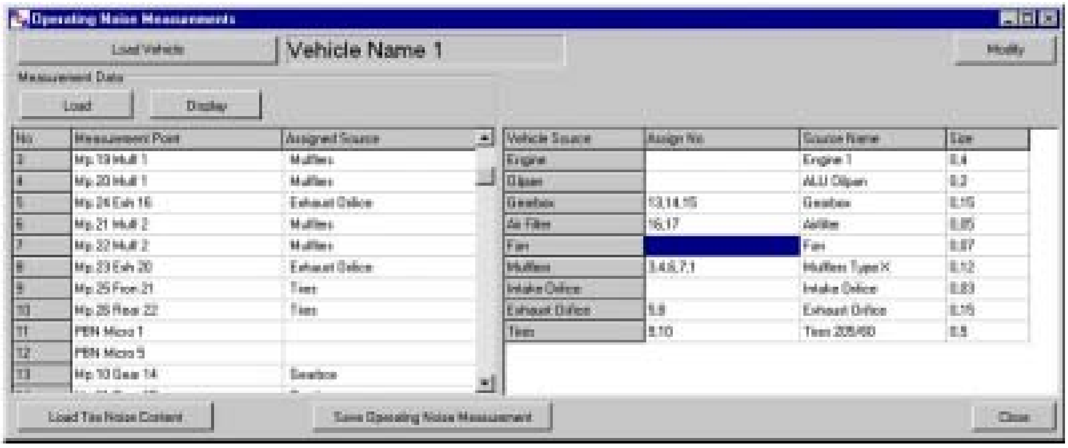


Vehicle Name 1

No	Measurement Point	Assigned Source
1	Noise Sour 2	
2	Mp.10 Gear 14	Gearbox
3	Mp.11 Gear 15	Gearbox
4	Mp.12 Gear 16	Gearbox
5	Mp.13 Air 17	Air Filter
6	Mp.14 Air 18	Air Filter
7	Mp.16 Fan 20	Fan
8	Mp.17 Oilp 21	Oilpan
9	Mp.18 Oilp 22	Oilpan
10	Mp.19 Muff 1	Mufflers
11	Mp.20 Muff 1	Mufflers
12	Mp.24 Exh 16	Exhaust Orifice
13	Mp.21 Muff 2	Mufflers
14	Mp.22 Muff 2	Mufflers
15	Mp.23 Exh 20	Exhaust Orifice
16	Mp.25 Fron 21	Tires
17	Mp.26 Rear 22	Tires

Vehicle Source	Assign No
Engine	18,19,20,23,24,25
Oilpan	8,9
Gearbox	2,3,4
Air Filter	5,6
Fan	7
Mufflers	10,11,13,14
Intake Orifice	21,22
Exhaust Orifice	12,15
Tires	16,17

Picture 3: Assigning microphone measurements during operation to different sources



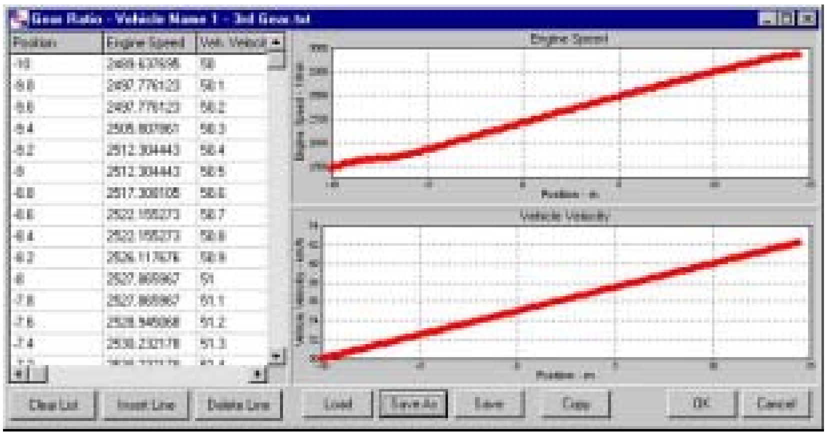
Vehicle Name 1

No	Measurement Point	Assigned Source
3	Mp.19 Muff 1	Mufflers
4	Mp.20 Muff 1	Mufflers
5	Mp.24 Exh 16	Exhaust Orifice
6	Mp.21 Muff 2	Mufflers
7	Mp.22 Muff 2	Mufflers
8	Mp.23 Exh 20	Exhaust Orifice
9	Mp.25 Fron 21	Tires
10	Mp.26 Rear 22	Tires
11	PBN Micro 1	
12	PBN Micro 5	
13	Mp.10 Gear 14	Gearbox

Vehicle Source	Assign No	Source Name	Size
Engine		Engine 1	0.4
Oilpan		ALU Oilpan	0.2
Gearbox	13,14,15	Gearbox	0.15
Air Filter	16,17	Airfilter	0.05
Fan		Fan	0.07
Mufflers	3,4,6,7,1	Mufflers Type X	0.12
Intake Orifice		Intake Orifice	0.03
Exhaust Orifice	5,8	Exhaust Orifice	0.15
Tires	9,10	Tires 205/60	0.5

The engine speed – vehicle position relation is taken from a real pass-by measurement (Picture 4).

Picture 4: Engine and vehicle speed versus position taken from measurement



Position	Engine Speed	Veh. Veloci
-10	2489.637698	50
-9.8	2497.776123	50.1
-9.6	2497.776123	50.2
-9.4	2505.807861	50.3
-9.2	2512.304443	50.4
-9	2512.304443	50.5
-8.8	2517.308105	50.6
-8.6	2522.155273	50.7
-8.4	2522.155273	50.8
-8.2	2526.117676	50.9
-8	2527.865967	51
-7.8	2527.865967	51.1
-7.6	2528.945068	51.2
-7.4	2530.232178	51.3

The PCA software offers the possibility to show the noise level of each source and to sum up these levels for a total level. By omitting a single source from this summation the noise reduction potential can be evaluated.

3.3 Example of PCA Analysis

The developed PCA software was applied to perform the analysis for a prototype vehicle which did not meet the current European pass by limit. As found in the analysis an intake system resonance creating a dominant intake orifice noise contribution was the reason for the high noise levels (in 2nd and 3rd gear).

The following diagrams (Figure 1 to 4) show the results of the PCA analysis. The top (black) curve shows the overall pass-by noise level calculated by the summation of all individual components.

The noise contribution of the components is drawn in different colours in the same diagrams. Obviously there is a strong dominance of intake orifice noise (dark blue line) for both vehicle sides and in both gears. Also the intake system itself (air filter box and piping) gives rather high contribution (dark magenta line).

Engine (red line), oilpan (dark green line) and gearbox (yellow line) have some contribution but compared to the intake system and orifice this contribution is still of minor importance.

Lowest noise radiation is calculated for the rear axle differential (brown line). Tire noise (light magenta line) is also no significant contributor (even in 3rd gear).

As can be seen the engine front (light blue line) has higher contribution at the beginning of the pass-by This is mainly due to the changing transfer function because the source level (engine) is of course increasing with increasing engine speed.

On the other side the exhaust orifice (cyan line) produces high noise contribution at the end of the test track with quite constant level. Although the distance to the microphone is increasing (reducing transfer function) this effect is partly compensated by the increasing orifice noise level.

Figure 1: Pass-by noise contribution (PCA) for 2nd gear right side

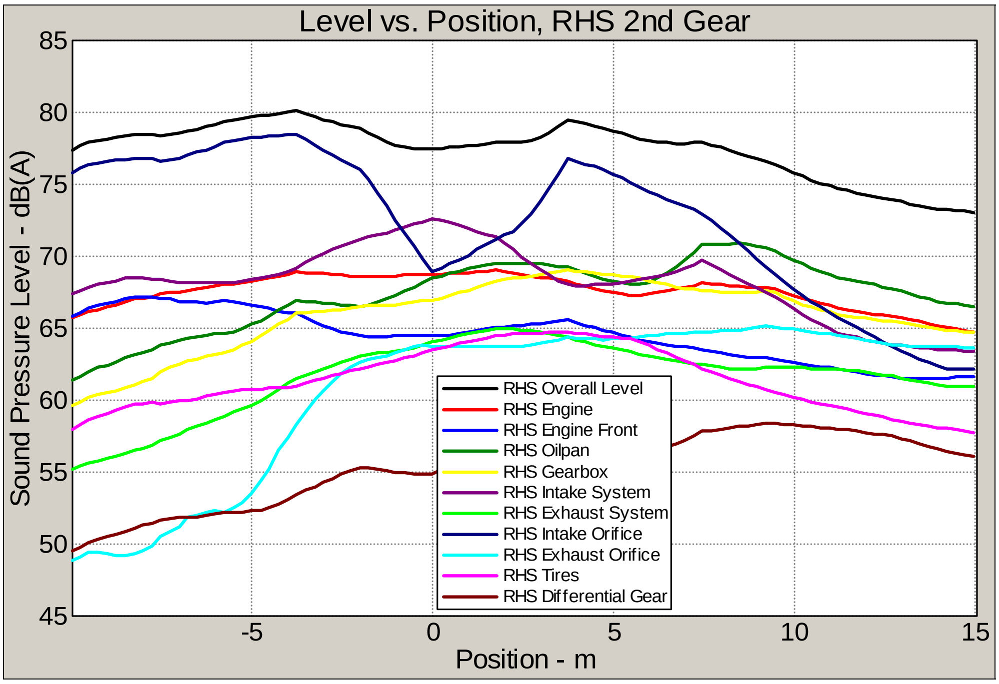


Figure 2: Pass-by noise contribution (PCA) for 2nd gear left side

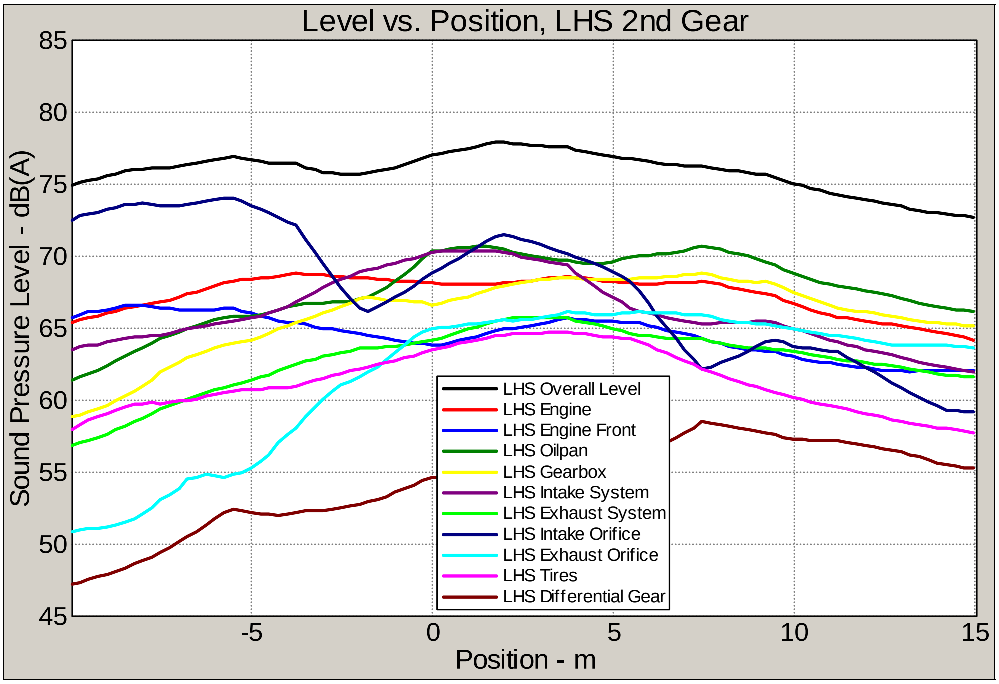


Figure 3: Pass-by noise contribution (PCA) for 3rd gear right side

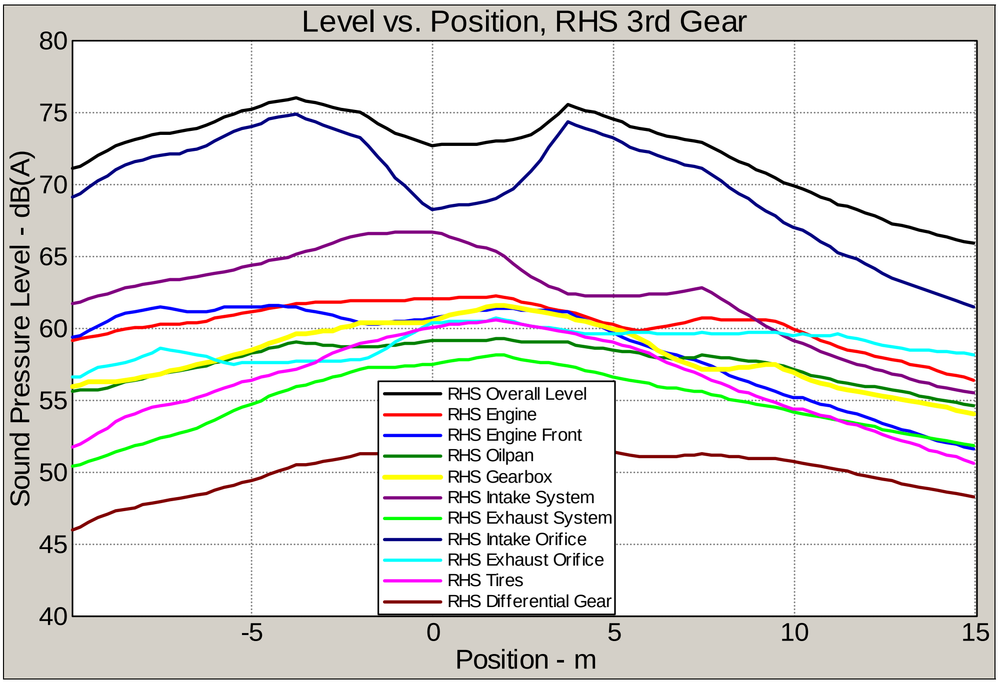
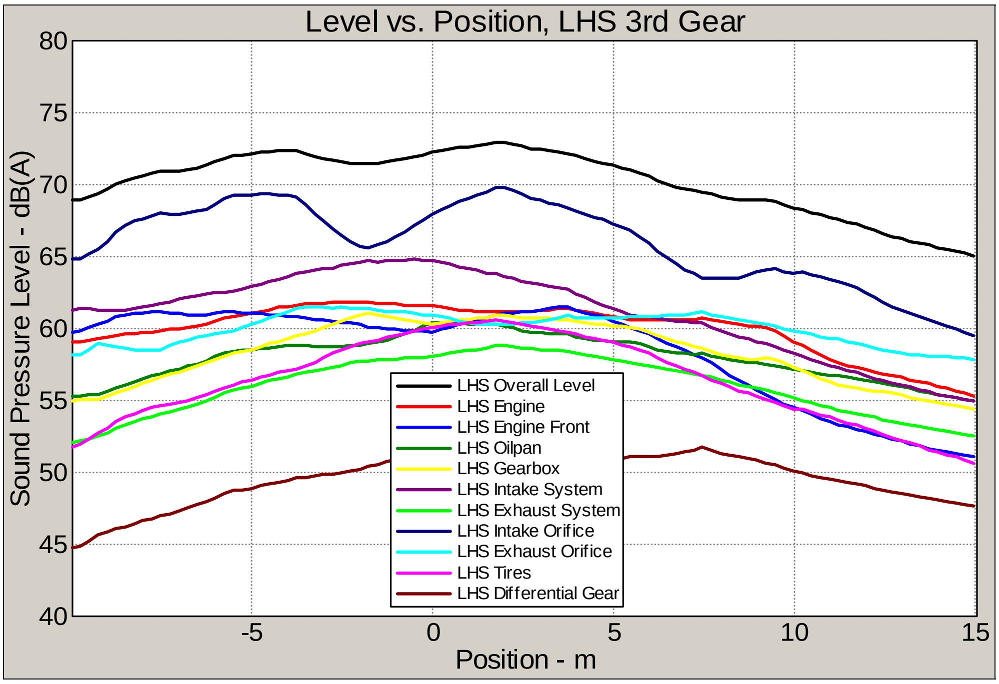


Figure 4: Pass-by noise contribution (PCA) for 3rd gear left side



If one cuts the above diagrams at the position of maximum total level one can determine the sound power contribution of each component. From this data the following pie chart diagrams (Figure 5 and 6) can be created showing the contribution in percent of total sound power.

Figure 5: Average 2nd gear pass-by noise contribution in percent

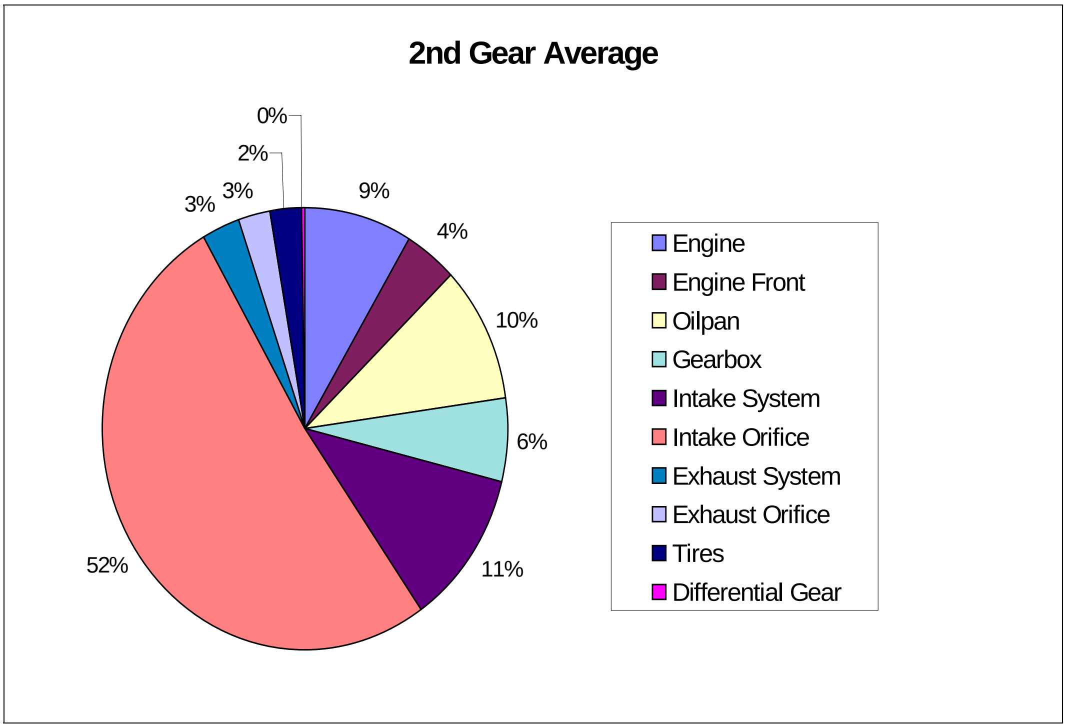
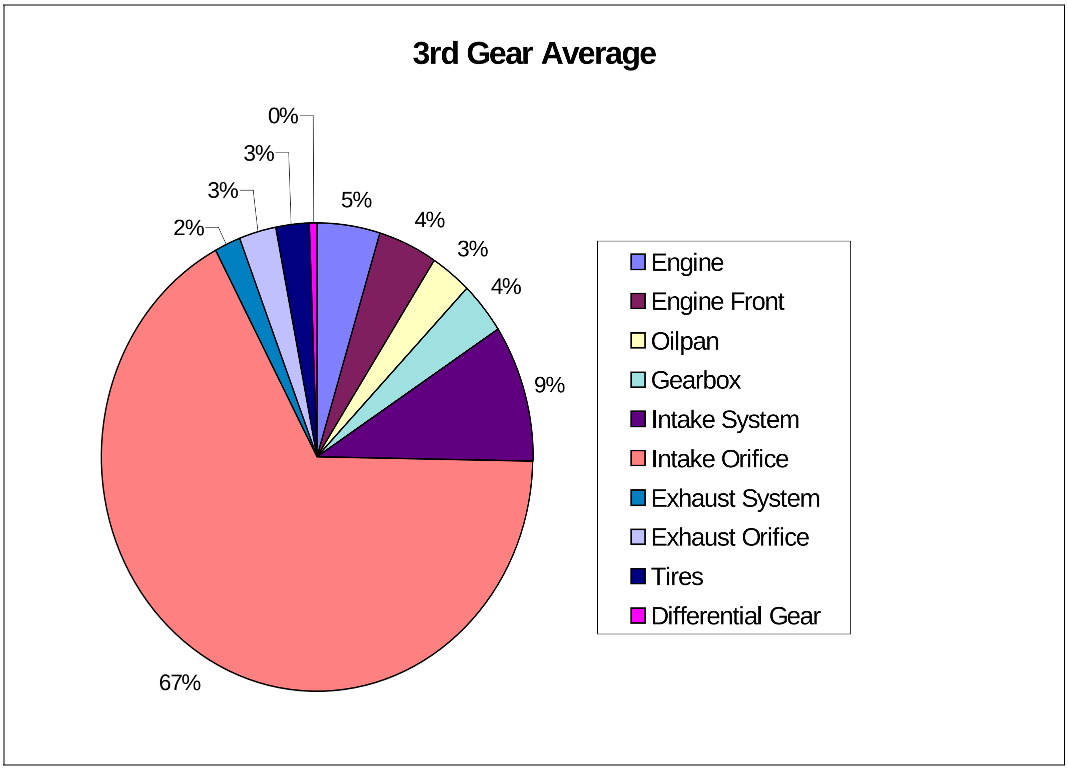


Figure 6: Average 3rd gear pass-by noise contribution in percent



So the first approach to reduce the pass-by noise must be the reduction of intake orifice noise. Only if the intake system noise is eliminated and the achieved noise reduction is not sufficient to meet the pass-by limit a shielding of other components should be applied. In the ranking of noise sources the engine, oilpan and gearbox follow the intake system. Therefore an engine compartment undershield may make sense as a second step.