Visualization of small design modifications using differential beamforming

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Designers and engineers use acoustic analyses in product development processes. Thereby their focus is not only on the absolute sound levels that are visualized in traditional beamforming maps. For evaluating the efficiency of modifications or alternatives they need to compare the impact of these changes on the acoustic characteristics.

If there are only small changes on the measuring object, the acoustic maps will be very similar. So a visual comparison and validation is difficult. Additionally, the differences may be covered by other strong sources that appear in both measurements.

This paper presents an approach for detecting noise sources in measurements of two similar measuring objects. Therefore the difference of two spectral beamforming maps is calculated and visualized in a result map. This frequency-selective result map contains only the acoustic information that varies in the original maps. The described method is illustrated by a series of example differential maps of modifications on a vehicle inside a wind tunnel. Finally, the informative value and possible fields of application are evaluated.

1 INTRODUCTION

The acoustic characteristics are important aspects of vehicle development. All automotive manufacturers try to optimize the acoustic perception of the driver and other passengers. Therefore, different design variants of single components, e.g. exterior mirror or windshield wipers, are tested and acoustically measured. A subsequent comparison of the measurement results allows a rating of the variants. For minimizing the noise generated by the airflow, these comparative measurements are run in wind tunnels, too. In order to analyse single parts here, the

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wind noise of the remaining vehicle must be suppressed. This is achieved by covering whole components with tape, which is a very time-consuming and thus expensive procedure.

A very common acoustic analysis technique is beamforming and the visualization of the results in an acoustic map. Therefore the acoustic measurement is done with a multi-channel microphone array. This allows the localization of sound sources in 2D and 3D space. If the beamforming is performed in the frequency-domain, the analysis and visualization can be done for selected frequency ranges.

The comparison of acoustic maps in the wind tunnel scenario may be difficult. If there is only a small modification, the map will look very similar to the reference map and the noise produced by the changed parts will be hard to identify. Furthermore, strong sources that exist in both measurements may cover weaker noise caused by the modification. Therefore we calculate the difference between two acoustic maps to visualize the variations.

Calculating the difference of measurement results and interpreting it to obtain new information is a widely-used method in science. So it is used for characterizing DNA by their UV thermal difference spectra[1] or to improve images of Acoustic Microscopes[2].

2 DIFFERENTIAL BEAMFORMING

A differential beamforming map is calculated by subtracting two input acoustic maps. The result is also represented as an acoustic map using a special color coding. An acoustic map is a set of points in 3D space. In case of 2D mapping, these points represent a projection plane divided into pixels. Each point is assigned a sound pressure value, calculated by applying a beamforming algorithm, e.g. Delay-and-sum[3] based on phase shift or cross spectral matrix (CSM).

To obtain suitable results, the measurements must be performed with the identical setup, which includes:

- same microphone array
- unmodified environmental conditions (e.g. ambient noise, temperature)
- no position and distance variations between array and object
- same sampling rate

In addition, the acoustic input maps must have the same parameters. Both maps must have the same point resolution and must be calculated with the same beamforming algorithm (including FFT parameters, e.g. block size, window function) over the same number of samples.

The result of the frequency-domain beamforming is the sound pressure decomposed into a set of coefficients, each representing a frequency range. The number of coefficients depends on the resolution of the Fourier transform. The difference is calculated by converting the values into sound pressure level (SPL) and subtracting the coefficients of the corresponding points in the input maps. So the difference sound pressure level (DSPL) value is positive if the SPL in the minuend map if higher and negative if the subtrahend map has a higher SPL. Points that represent the same noise source in both input maps cancel each other out to zero.

The result acoustic map is merged by calculating the arithmetic mean of the DSPL values of the coefficients that correspond to the frequencies of interest. For the visualization, a symmetric color coding is used, ranging from –a to +a, where ’a’ is the maximum absolute difference sound pressure level of the map. The values close to zero are colored white or transparent whereas two differing color gradients visualize the positive and negative values.

3 RESULTS

Fig.1 and 2 show the beamforming maps of two measurements of a car in a wind tunnel. The measurement setup was identical in both cases, except for the exterior mirrors, which were removed in the second recording. Because the mirrors are big obstacles in the wind flow, they are clearly visible as strong sources in Fig.1 and missing in Fig.2. All other sources appear in both maps.

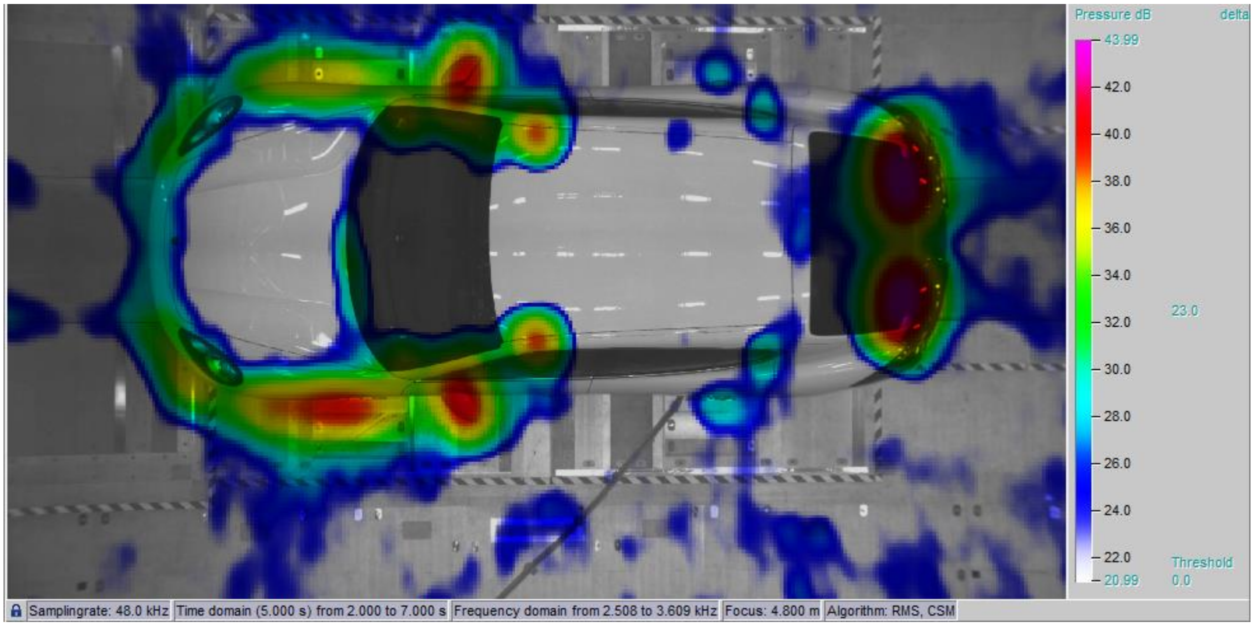

Fig.1 – Acoustic map of a car in a wind tunnel, calculated with CSM and block size 4096 samples

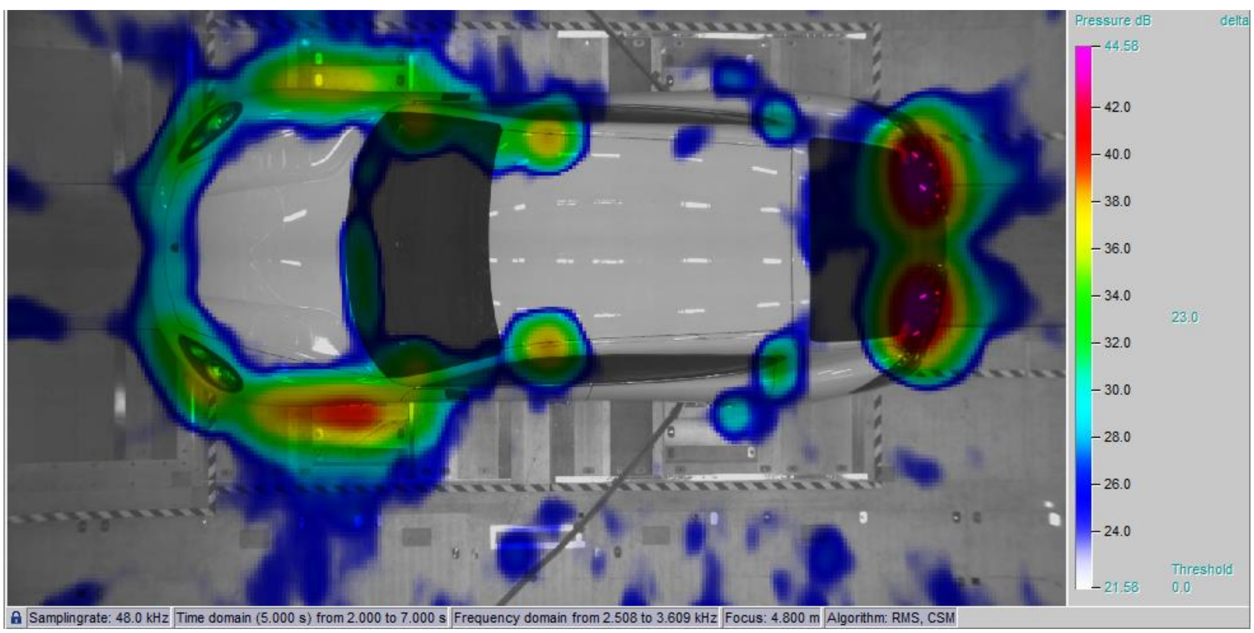

Fig.2 – Acoustic map of a car in a wind tunnel, exterior mirrors dismounted , calculated with CSM and block size 4096 samples

Calculating the differential acoustic map of Fig. 1 and 2 gives the map shown in Fig.3. Because the measurement with mirrors is the minuend, the mirrors appear as positive difference of 17dB. Whereas this outcome can be expected by visually comparing the source maps, the result also shows a negative difference that is not so obvious at first sight. The noise behind the rear of the vehicle is about 10dB louder in the second measurement.

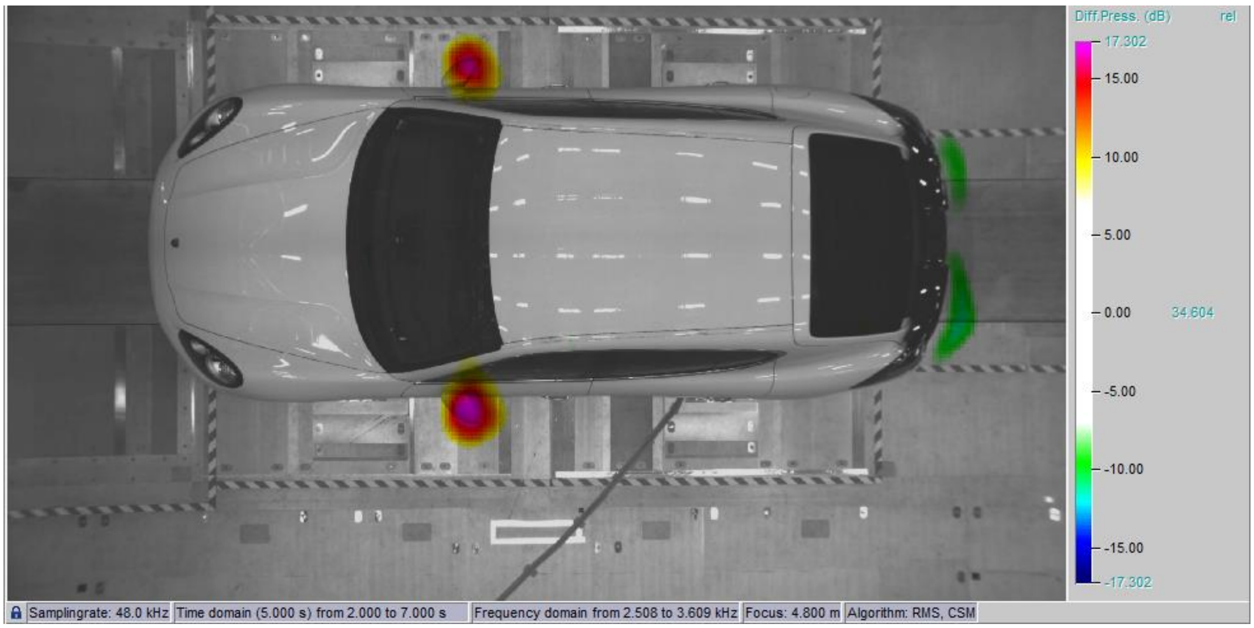

Fig.3 – Differential acoustic map calculated from Fig.1 and 2

In a second wind tunnel test series the size of the modification was reduced to prove the applicability of the method for small differences. Therefore a screw was taped down on the top side of the left mirror (Fig. 4). Because it resided in the air flow, the screw influenced the aerodynamic properties of the mirror and thus the generated noise. Again, nothing else was changed on the remaining measurement setup.

Fig.4 – Screw taped down on left mirror

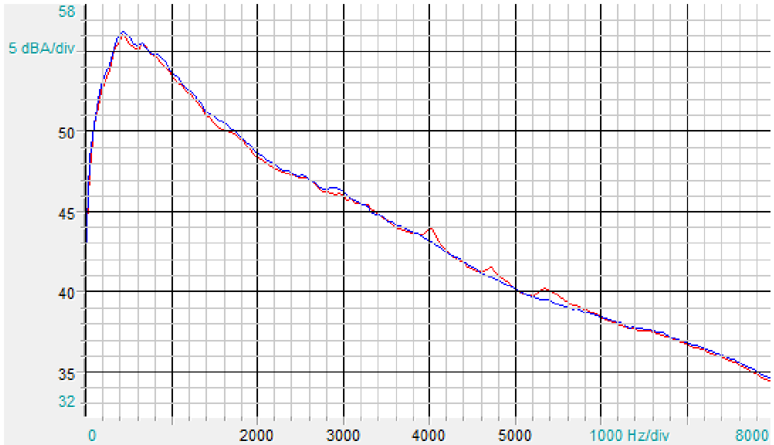

Fig.5 – Average spectra of measurements without modification(blue) and with screw on mirror(red)

Fig. 5 shows the frequency spectra of both measurements, each representing the average spectrum of all microphone channels. The comparison of both lines indicates that there are only small differences at specific frequencies. The red line contains three peaks at 4.0 kHz, 4.7 kHz and 5.3 kHz, which are probably generated by the screw. For the verification of this assumption, the differential beamforming was applied for these peak frequencies.

The examples presented here cover the frequency range from 4.5 kHz to 4.9 kHz, so the second peak at 4.7 kHz is included. Fig. 6 reveals the wind noise in the area around the A-pillar with the unmodified mirror. Two main sources can be identified: the wipers on the windscreen and the mirror. The acoustic map of the measurement with the taped screw (Fig. 7) indicates the mirror as loudest source. The wiper noise is still present but not so obvious, because it is covered by the mirror noise.

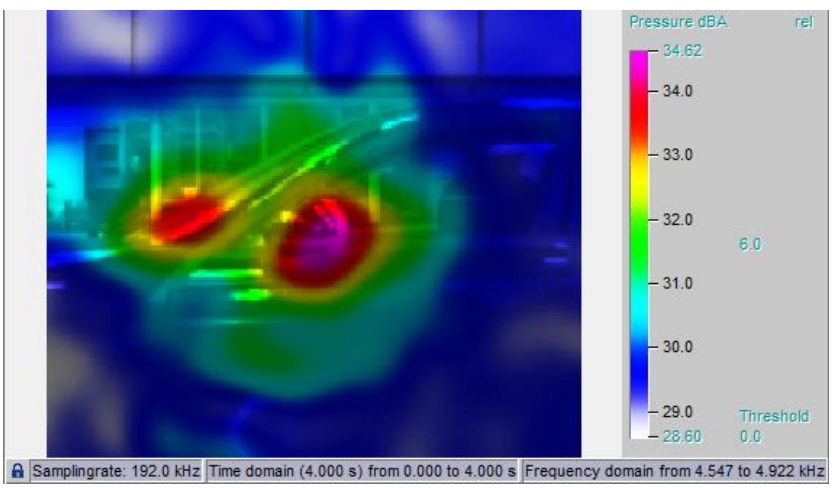

Fig.6 – Acoustic map of unmodified A-pillar in wind tunnel, calculated with CSM and block size 4096 samples

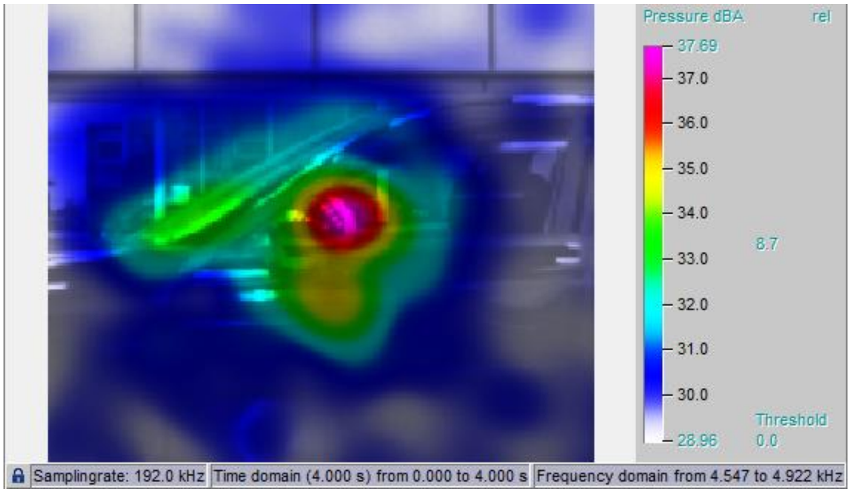

Fig.7 – Acoustic map of A-pillar with screw on the mirror in wind tunnel, calculated with CSM and block size 4096 samples

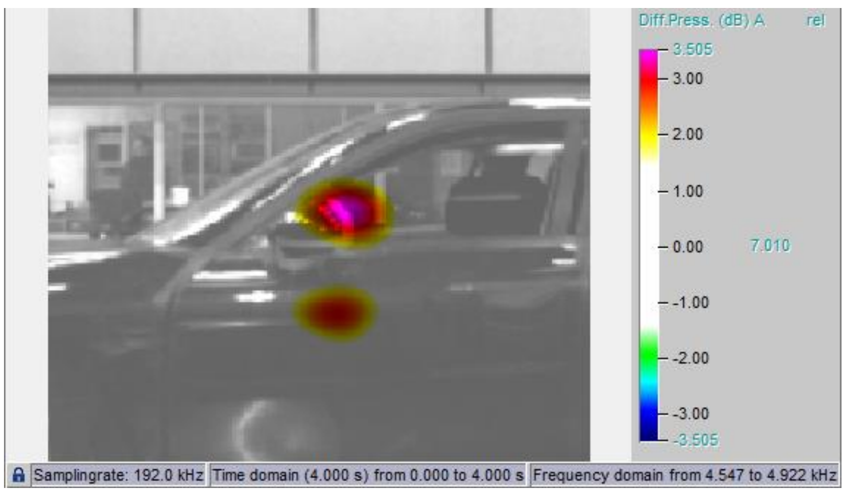

Fig.8 – Differential acoustic map calculated from Fig.6 and 7

The differential beamforming map in Fig.8 depicts the position of the screw very precisely at a difference sound pressure level of 3.5 dBA at the selected frequencies. In addition, the reflection of this source on the door becomes visible. The noise generated by the wipers and the mirror cover is eliminated by the subtraction and thus not visible in the result map. Analyzing the other peak frequencies at 4.0 kHz and 5.3 kHz produces similar results (Fig. 9a, b). Again, the screw is the main difference. As Fig. 9c shows, it can also be identified for frequencies that are not recognizable as a difference in the spectrum diagram.

All these examples were calculated using short time FFT with a block size of 4096 samples resulting in a spectral resolution of 46.88 Hz at a sampling rate of 192 kHz. As described in section 2, the subtraction is done per coefficient. To evaluate the influence of the frequency resolution on the result map quality, the acoustic maps in Fig. 5-7 have been calculated with block sizes from 2048 to 32768. In all cases the differential acoustic maps were almost identical, clearly pointing out the screw on the mirror.

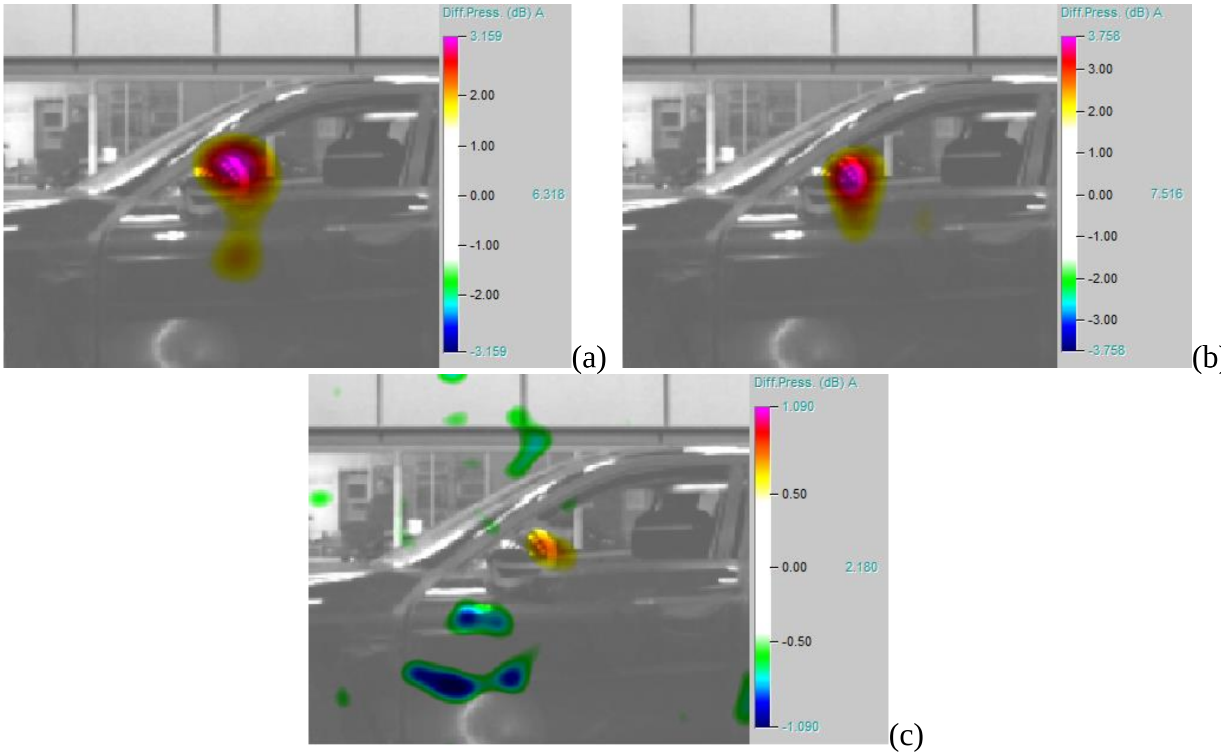

Fig.9 – Differential acoustic map of A-pillar calculated with CSM and block size 4096 samples, frequency ranges 3.8-4.2 kHz (a), 5.1-5.5 kHz (b) and 6.3-6.7 kHz(c)

4 CONCLUSION

The examples presented here demonstrate that differential beamforming maps can be used to visualize differences between similar acoustic measurements. The method allows the detection of very small modifications by location and the difference sound pressure level that they generate. Because steady sound sources that appear in both measurements are eliminated, this technique is well-suited for the use in wind tunnels. The noise of the unmodified vehicle parts is canceled out, so no covering and taping is required.

Future work may be done on combining differential beamforming with the results of correlation analysis[4] to compare the noise transmission into the cabin of the vehicle. An alternative calculation approach is to subtract the cross spectral matrices of both measurements to generate a differential map.

5 ACKNOWLEDGEMENTS

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6 REFERENCES

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