# Validation of a measurement based Area Contribution Analysis

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## Abstract

The Automotive Industry is in need of effective NVH measurement methods to optimize the design of isolation and damping concerning weight and cost constrains. In order to gain better knowledge on the contribution of each panel from the interior it is imperative to find a practicable method of analysis in the early prototype stages of a vehicle. Such a gap can be achieved through the use of new acoustic measurement technologies. Using the Microflown-element [3] it became possible to grasp the particle velocity close to any surface based on measurements. Its use in a transfer path method allows the quantification of surface contribution in the cabin. A simple example below shows validation details of such a process through a comparison between a direct measurement and a TPA Synthesis. This example depicts the critical range of the mid frequencies (100-3500Hz). The precision and usability of this method will be discussed moving forward based on this special designed setup.

## Introduction

The automotive industry uses acoustic masking like the "window method" to quantify the contributions of different subsystems of the cabin. The drawback is the modification of the inner cabin acoustical properties. An extensive measurement is also required for achieving the information's needed. These results are not necessarily meaningful in the critical frequencies under 400Hz. Another point is the unavailability of narrow band statements to visualize the modal behaviour. This research aims on the development of a contribution method which covers the upper modal-, the middle- and the high frequency range without having to modify the car due to future shortages of prototype availability. Methods for the description of the source strength have been introduced in the past. Two examples that use the information from an Microflown sensor are the surface velocity method [1] [2] and the sound power method [4] [5]. In the sound power method the phase information is lost. So the cross talk between sub surfaces isn't taken into account and therefore it can't be used in the lower frequency range. In this article it is focused on the surface velocity method due to the preservation of the phase information.

## Description of the surface velocity method

The established relation between the sound pressure $p_\omega$ at any point was observed from [6] and is given with

$$p_\omega = -ik\rho c \int_\Gamma u_\omega(x_0, y_0) G_\omega(x, y, z|x_0, y_0, 0) d\Gamma \quad (1)$$

and is the basis for this surface velocity method. Here $u_\omega$ represents the normal velocity on the observed surface $\Gamma$. The Green Function $G_\omega$ characterises the transfer property from the active surface to the arbitrary point $p_\omega$. Due to measurement the regarded surface has to be discretised in order to get this information through sensors in the real mock-up. So the surface velocity is measured with a calibrated Microflown particle velocity sensor at discrete points over the surface. Experimental transfer functions at discrete points are used to approximate the Green function. The reciprocal way is used. A big advantage of this process is the fact, that the interior of the car - and therefore the soundfield - does not have to be modified like e.g. with the conventional window method. To gain a feeling of the potential and the accuracy of this method, a basic measurement setup will be analyzed in the following parts. Comparisons have been done with the traditional window method [2]. In this approach a general setup should be found, which gives the opportunity to not loose a big goal of this analysis method - the unsophistication of interior car panels.

## Measurement setup

The following studies are performed at the BMW acoustic facilities in Aschheim. The following measurements are performed in a window laboratory with a flexible window size (max. window is 3,5m x 2,15m, Figure 1). In daily business this laboratory is used for transmission loss measurements. To achieve shorter testing times in standard procedures the Semi Freefield Room is equipped with a 7 axes robot.

As probe a 1m$^2$ steel metal sheet with a thickness of 0.8mm is used. This metal sheet is excited by an airborne white noise in the reverberant room and is the only radiating surface. The measurement equipment is placed in the anechoic room (see Figure 2).

A sensor Array with 16 Microflown PU-Mini probes is used (Figure 3). Two measurement steps are necessary and the PU-Array is used in both measurement steps due to its design. In the Study the sensors have been arranged in two different spacing's on the array to get some information on the influence of the discretisation on the measured results.

In operational mode the particle velocity in the near field is measured with the built in Microflown element. Mul-

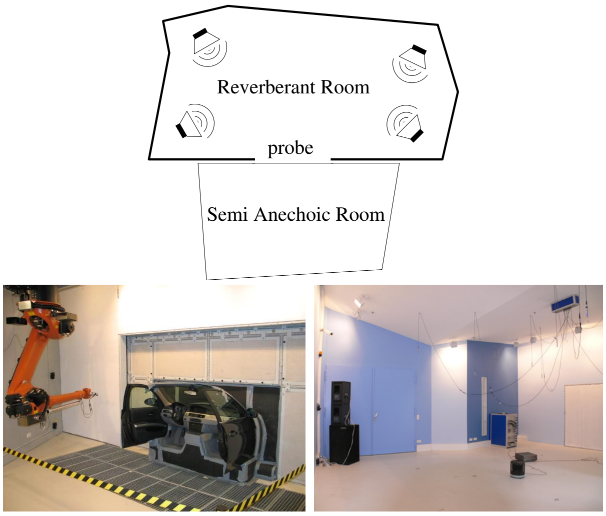



**Figure 1:** Window-Laboratory at BMW

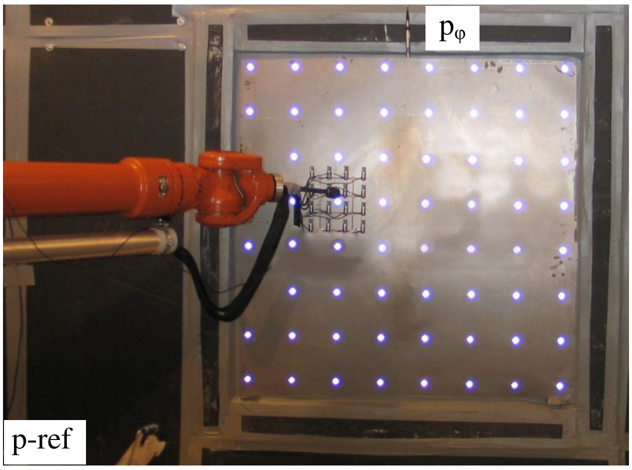



**Figure 2:** Measured probe during a scan

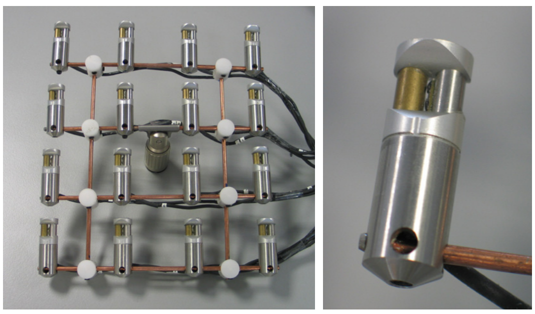


**Figure 3:** PU-Mini Array and PU-Mini Probe

tiple measurements are performed during the scanning process of the plate. So a phase reference was necessary - in this case - a Microphone close to the surface ($p_\varphi$, see Figure 2). Additionally a microphone (p-ref) is placed at the point of interest. This information allows a later comparison with the calculated sound pressure. During the measurement of the transfer function the internal pressure microphone of the PU-Probe is used to determine the transfer path to the emitting point like source with the radiated Volume Velocity Q (Figure 4, 5-b). The volume velocity is quantified with a low-dB Microflown particle velocity sensor.

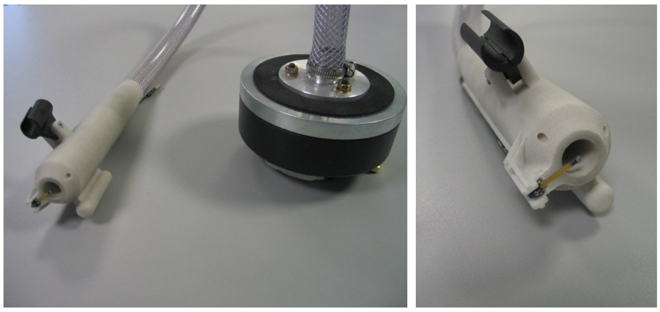


**Figure 4:** Used point like source

To get some information concerning the accuracy of the absolute position the array is mounted on the available 7 axes robot in the laboratory. This allows an accurate placement of the array itself and gives the opportunity to get a feeling on the influence of the distance from array to radiating surface.

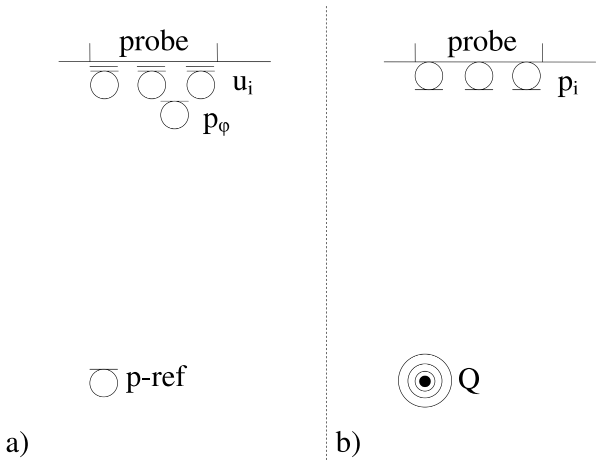



**Figure 5:** Measurement Setup: a) Operational Measurement, b) Transfer Path determination

## Analysis

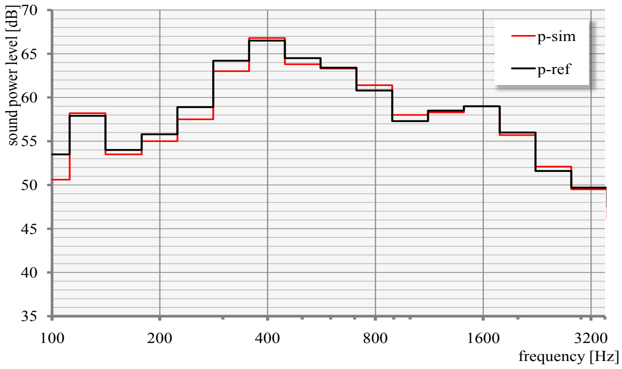
In the following section a few measurement results are shown. Some answers on the following aspects will be given:

- Accuracy of the method in narrow and $1/3^{rd}$ Octave band;
- Influence of the discretisation on the calculated result;
- Relevance of the scanned section plane concerning the structure surface.

## Accuracy of the Method

First a comparison of the calculated and the measured signal should be done. The robot was adjusted to scan the probe directly above the surface. Due to the design of the PU-Mini probes the minimal distance between the plate and the particle velocity sensor is 10mm. Figure 6-a shows this measurement in $1/3^{rd}$ Octave band. The measured and simulated signals show a quite good compliance. Also in narrow band both signals show a good correlation (Figure 6-b).

a)




b)

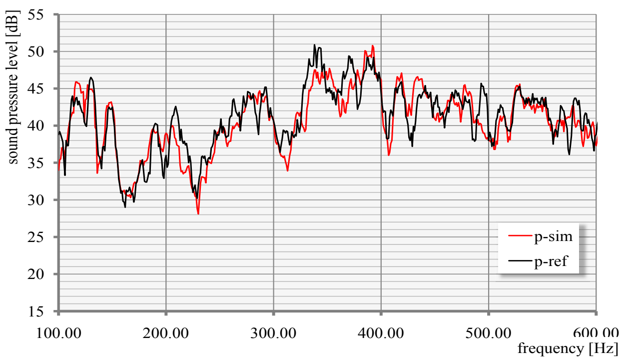



**Figure 6:** Comparison of calculated and measured sound pressure: a)$1/3^{rd}$ Octave; b) Zoom at the frequency range 100-600Hz

## Influence of the discretisation

The results shown before have been done with a distance of 50mm between the probes. In the following 2 charts distance is varied from 50mm (Figure 8) to 100 mm (Figure 7). In the 100mm configuration the simulated result starts to drift at 2kHz. This is equivalent to a point density of 1.7 measured points per wavelength. After a refinement of the mesh to 50mm (equals a drift frequency of 4kHz with a density of 1.7 points/$\lambda$), the results show a good coherence up to 4kHz.

To gain some better results in the whole frequency range and to improve the effectiveness of this method the focus has to be laid on this subject again. It is an essential factor for the usability in daily business.

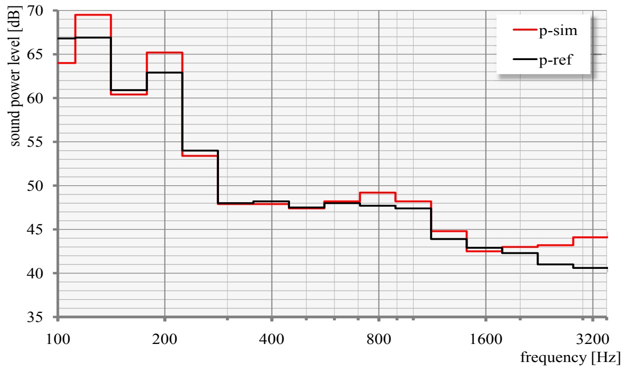



**Figure 7:** Calculation with a discretisation of 100mm

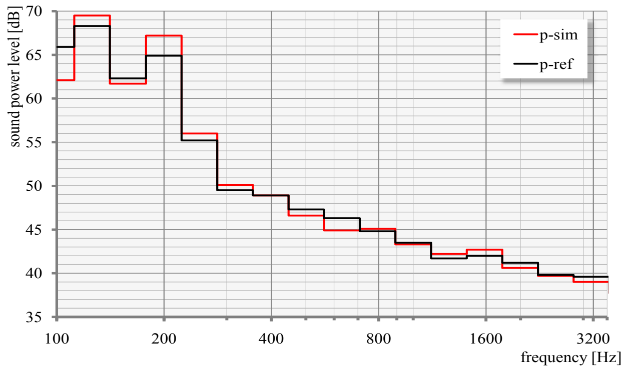



**Figure 8:** Calculation with a discretisation of 50mm

## Relevance of the scanned section plane concerning the structure surface

The application of the array in a car cabin does not allow a precise positioning of the distance between the section plane and the surface. Therefore it is worth to do some studies about that influence. In Figure 9 a set of simulations with different distances are shown. The used velocity- and transfer path signals have been recorded in the same section plane. A declination of the simulated results is clearly visible.

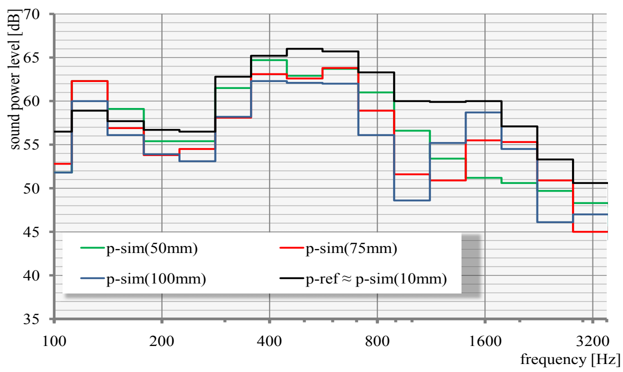



**Figure 9:** Influence of the distance between the measured object and the section plane in $1/3^{rd}$ Octave

To improve the simulated results the measured particle velocities of the different layers are combined with the transfer functions from Figure 6 at a distance of 10

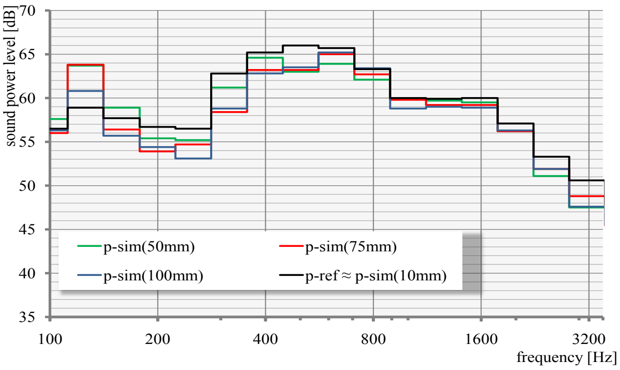



**Figure 10:** Corrected influence of the distance between the measured object and the section plane in $1/3^{rd}$ Octave

mm. An increasing of the simulated quality in the higher frequency range is obvious. This shows the importance, to keep the boundary conditions of $u_\omega(z = 0) = 0$ during the approach of the transfer function.

## Conclusion

A measurement setup for an accurate validation and a base for extended studies of boundary conditions for the particle velocity method was presented. A measurement under ideal conditions shows a good correlation with the expected signal. Two boundary conditions have been varied to gain some information's about the influence. The distance of the sensors results in a variation of the simulated signal. Due to an optimized application in the car these conditions need to be reviewed. In a practical use of the velocity method, caution is required in the positioning of the sensors. Other methods should be valued concerning the stability of the results. The improvement of this influences - especially with sight on a measurement in a car cabin - needs to be developed.

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