

# Scan & paint for acoustic leakage inside the car

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## ABSTRACT

Leakage ranking of vehicle cabin interiors is an important quality index for a car. Noise transmission through weak areas has an important role in the interior noise of a car.

Nowadays the acoustic leakage inside a cabin can be measured with different techniques: Microphone array-based holography, Transmission loss measurement, Beamforming analysis, Sound intensity P-P measurements and ultrasound waves measurements. Some advantages and limits of those measurement approaches for quantifying the acoustic performance of a car are discussed in the first part of this paper.

In the second part a new method for fast leakage detection and stationary noise mapping is presented using the Microflown PU probe. This method is called Scan & Paint. The Microflown sensor can measure directly the particle velocity which in the near field is not affected by background noise and reflection. This makes the sensor very suitable for measurements inside a complex and reactive environment like the interior of the car.

A camera is used to film the sweep measurement procedure of some surfaces in the cabin interior of a Toyota Avensis. The audio data is processed and synchronized with the video data. A velocity or intensity colormap can be calculated for the different interior parts of the car under test.

## EXISTING METHODS

A short description with features of the several known methods to determine the acoustic leakage inside a car is summed below.

### Microphone array based Holography

Near-field Acoustical Holography (NAH) is a well known visualization technique that requires free-field conditions and needs a planar measurement area that fully covers the radiating surface (see e.g. [6]), this is required to avoid spatial windowing effects. With so called 'patching techniques' it is possible to visualize sources that are larger than the array, see e.g. [5].

Approximate free-field conditions can be obtained by the use of absorbing materials behind the array.

Other drawbacks of this method are:

- The need of a large array of microphones that has to be positioned close to the surface of the sound radiating object
- Complex and time consuming set up.
- The high equipment costs
- Strong theoretical background knowledge is required.

Due to all the strict requirements the results are sometimes not accurate, and the method works in a limited bandwidth.

### Transmission loss measurements

The transmission loss is one of the most systematic approaches available, see e.g. [4]. The method requires expensive facilities; the suite is generally mounted between one reverberant room and one anechoic room. The sound intensity is measured in the anechoic environment.

The first noise transmission is called direct transmission. The second transmission comes through the surrounding structures. This type of noise is called flanking transmission. The noise can travel through the flanking paths and can affect the intensity measurements.

Moreover the transmission loss suite is time consuming and not freely available.

It is impossible to do this type of measurement in situ (i.e. driving the car on the road).

### Beamforming analysis

The most common far field localization techniques are beamforming methods where an array of microphones is placed far from the source. Beamforming with a planar array requires just like NAH free-field conditions and all sources to be in front of the array. It is possible to use sphere of microphones so that sources can be found in all directions.

The array of spaced microphones act as a highly directional microphone and the source distribution can be measured relatively easily.

The method requires less set up time than holography and requires less education. However in the context of this application there are some drawbacks:

- Equipment costs is still high due to the amount of microphones
- Results are not always accurate due to reflections.
- The absolute source strength cannot be obtained and
- the method works for higher frequencies (depending on the microphone spacing and the geometry of the array).
- The spatial resolution of approximately one wavelength, which will be very poor at low frequencies.

Because of the operational bandwidth of the above mentioned methods it is common to use one array of microphones and hardware for both the beamforming and holography. These methods require restrictions of the acoustic environments. Spherical beamformer arrays have been introduced to avoid the requirement for free-field conditions and to be able to map sources in all directions. Reflections will, however, also appear as sources, and resolution is still a severe limitation at low frequencies.

### **Sound intensity (pair of microphone) based**

The traditional intensity microphone probe (the P-P probe) measures particle velocity and the sound intensity based on the pressure difference between two phase matched microphones. The advantage of this method is the lower cost than the previous methods and the probe size is more suitable for the cabin interior. However the strong reactive environment inside the car leads to a high P/I index [1], which results in a wrong estimation of the velocity and the sound intensity.

To reduce the reactive field inside the vehicle absorbing material can be used around the measurement window. This is time consuming and prevents in situ measurements.

Also the frequency range of measurement is dependent on the spacing between the two microphones.

In more costly and time consuming applications the roof and the doors of the car can be literally cut away. The cabin interior so opened reduces the reflections and lower the P/I index. This destructive method changes the vibrational properties of the chassis and the airborne leakage cannot be tested.

One alternative method which avoid P/I index problems to measure leakages consists in exciting the car from the interior with a loudspeaker. The car is in semi anechoic condition and the probe is swept out from the car to find leakages. With this method only an indication for very simple leakage path can be detected as the exact position from the interior remain unknown. Moreover only

airborne leakage can be detected and the car cannot be tested under driving conditions.

### **Ultrasound waves measurements**

An ultrasonic leak detector consists of a sound emitting source (transmitter) and a receiver. The emitter is usually positioned inside the cabin of a close vehicle and then commercially available high frequency microphones are used to scan the window seals and doors for any acoustic emission passing through any leaks, (e.g. [3]).

The main reason for investigating the use of the ultrasonic spectrum compared with the audible spectrum for detecting leaks is because the ultrasonic spectrum is often void of any significant background noise contamination.

The complex structure and the non-straight paths typical of the cabin interior make this method not applicable for the entire interior. Also the test cannot be performed under driving conditions and only the airborne leakages can be detected.

### **THE SCAN & PAINT METHOD**

Measurements in enclosed non anechoic environments (like inside a car) and measurements with extraneous noise sources that cannot be shut off are usually very difficult to handle with traditional measurement methods.

The direct measurement of particle velocity makes it possible to measure in these acoustic environments with a high level of background noise and reflections [1], [2] and [7].

In the near field of a sound source (at low frequencies) almost all the energy is kinetic energy (velocity). With a PU probe the velocity from the surface is directly measured. Velocity is much less affected by background noise than pressure because:

- The impedance of many surfaces is high, and close to such reflecting objects the sound pressure due to the background noise will increase (~6dB), while the velocity measures almost no background noise. At the surface, most potential energy (pressure) and kinetic energy (velocity) will be converted to potential energy, because the surface itself will not move due to external noise sources.

- In the acoustic near field there is a high particle velocity level compared to sound pressure due to the vibration of the surface itself.

- The directivity pattern of the sensor: the velocity sensor has a figure-of-eight sensitivity, whereas sound pressure transducers are omni-directional. This means external sources from other directions are significantly reduced.

It is not always possible to use the velocity method at high frequencies if the probe-surface distance is large (near field conditions are not met anymore). The intensity can be used instead. Compared to P-P intensity probes, P-U intensity probes are small and have no spacing problem, but more importantly P-U probes can be used in environments with high levels of reflections or background noise (no p/l index problems) [1], [2]. Other advantages of the sensor are also the frequency bandwidth and the small dimension. The Microflown can measure from 20Hz. to 20kHz. without hardware modifications.

In the Scan & Paint method the probe is swept close to the surface and at the same time the audio data is measured also video is captured. With software the probe position is recognized from the video frames in the screen and at that position the sound field is represented. Because the sound probe captures both sound pressure and particle velocity it is possible to measure the particle velocity field and the sound intensity field directly.

The method is fast (low set up time and low acquisition time), it does not require much training to be able to work with the system, it is broad banded (20Hz-20kHz), the influence of reflections or extraneous noise is low.

The Scan & Paint merges the advantage of the sensor in term of acoustic benefits with a methodology that allow a fast processing session with very high resolution measurements.

## MEASUREMENT SET UP

Two tests on a Toyota Avensis are shown in this paper. The mapping of the velocity and intensity is made from the interior of the cabin.

The first test is performed under driving condition at two different speeds: 40km/h and 100km/h.

The second test is done only with airborne excitation with a white noise source loudspeaker positioned outside from the car.

A leakage is artificially created through the rear window with a small aperture, see Figure 1.



Figure 1: Leakage created through the rear window with a small pivot.

## Measurement in driving condition (40km/h)

The leakage is scanned during a test drive at 40km/h. The complete measurement time was 30 minutes. From this time, 24 minutes was required to fix the camera, start driving and get back, the measurement time was 1 minute and the processing time was 5 minutes.

At low frequencies the leakage is easily detected, see Figure 2.



Figure 2: Velocity map 200-2kHz at 40km/h.

At higher frequencies also the bottom part of the window shows important leakages, see Figure 3.

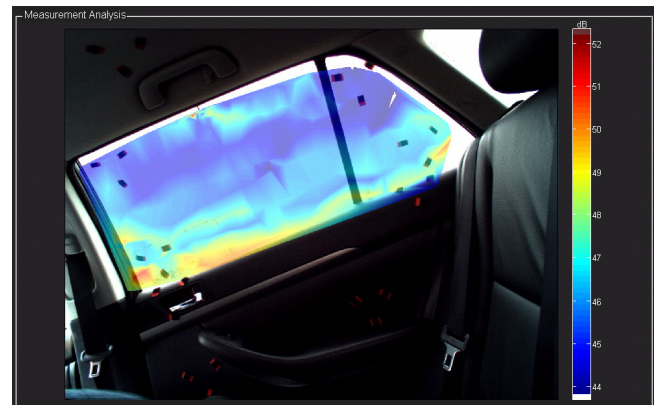


Figure 3: Velocity map 2kHz-10kHz at 40km/h

The amount of noise is calculated as the particle velocity integrated over the surface. This results in a volume velocity.

## Measurement in driving condition (100km/h)

At low frequency the leakage is again easily detected, see Figure 4. Because the camera was placed, the complete measurement time was 10 minutes.



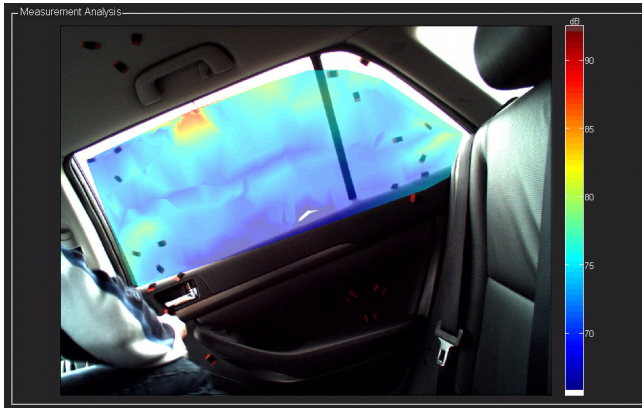


Figure 4: Velocity map 200-2kHz at 100km/h.

At higher frequencies also the bottom right part of the window shows important leakages, see Figure 5

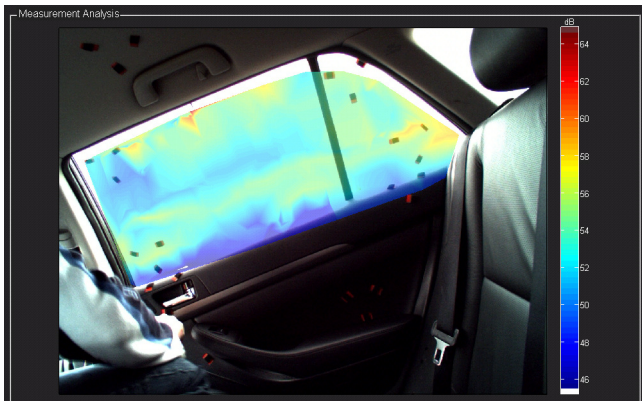


Figure 5: Velocity map 2kHz-10kHz at 100km/h.

## MEASUREMENTS WITH A LOUDSPEAKER

A loudspeaker is positioned at the right side of the car approximately 2m distance, see Figure 6.



Figure 6: Set up for the measurement with the loudspeaker.

## Velocity distribution inside the cabin (loudspeaker)

The particle velocity distribution measured inside the cabin due to the sound pressure outside the vehicle is shown in Figure 7 and Figure 8. The leak is easily localized as can be seen. The distribution however is different than the in situ situation.

The high frequency (Figure 8) particle velocity distribution shows the leakage but not the other radiation areas that can be seen in the driving condition (Figure 3, Figure 5). It can therefore be concluded that loudspeaker methods do not give accurate results and that driving conditions are preferable.



Figure 7: Velocity distribution inside the cabin 200-2kHz.



Figure 8: Velocity distribution inside the cabin 2kHz-10kHz.

Another disadvantage of the loudspeaker method is that can be assumed that the sound field does not represent driving conditions.

The sound pressure distribution outside window is shown in Figure 9 (this is a 10 minutes measurement; the camera can be kept inside). The sound level is not distributed in a uniform manner.

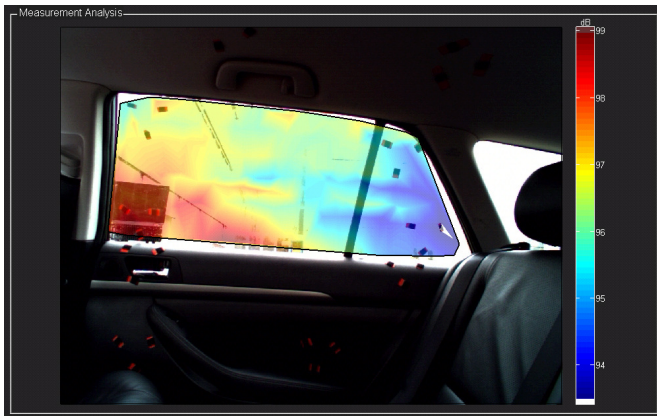


Figure 9: Pressure distribution measured over the window from the outside of the car (50Hz-10kHz).

If one chooses to use the loudspeaker method and localized sources should be ranked one can choose to use the measured outside sound pressure distribution to correct the measured velocity distribution.

## DISCUSSION

The Scan & Paint method is applied to visualize leakage noise inside a car. The most obvious way to demonstrate this is creating a leakage by making a small hole and show that this leakage is found. This is done, but more is learned in this experiment.

It showed that using a loudspeaker is much more work than an in situ test and that the results with the loudspeaker do not provide all relevant information. The source ranking cannot be done with a loudspeaker. It showed that the leakage is not dominant at high frequencies at 40km/h and 100km/h.

Apart from this it is difficult to create a sound field with a loudspeaker that resembles the real situation.

For these reasons we think that in situ test is the best way to get useful results.

## CONCLUSION

The Scan & Paint is a fast tool to localize stationary sound sources. The measurements can be done in very complex and reactive environment like the cabin interior because PU probes are used.

A simple scan of the surface is recorded by a video camera and synchronized with the audio data. The position of the probe can be recognized by the video and the color map can be calculated in very high resolution.

The method can be applied in real driving conditions (both structural and airborne excitation) and in a test room with only airborne excitation.

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