Capturing a noise source in an interior enclosure

F. Deblauwe[1], M. Robin[2]

[1] LMS International, Interleuvenlaan 68, 3001 Belgium, Email: filip.deblauwe@lmsintl.com
[2] MICROdB, 7B, allée Claude Debussy, 69130 Ecully. France, Email: mr@microdb.fr

Introduction

Sound source localization (SSL), such as NAH and beam-forming, have been around for the last decennia. SSL techniques have been mainly used for free field conditions and only the last couple of years these techniques have found their way into interior acoustic applications where non-free-field conditions are met.

In this paper a two step test procedure is proposed to perform a detailed interior SSL localization. In a first step, a solid spherical antenna is used to perform a SSL on the complete interior compartment. The uniqueness of this solution lays in the fact that the SSL propagation is not only based upon a beam-forming solution, but takes also into account the acoustic diffractions that happen around the solid sphere. This method, solid sphere and processing, is a patented technique owned by MicrodB & Airbus. The first step gives an overview of all sources present in the interior enclosure, but with a limited spatial resolution. In a second step this spatial resolution is improved by taking a second measurement focusing in at certain areas of the enclosure. For these measurements a cylindrical array is used and the data is processed using focalization. Focalization is a beam-forming technique adapted for measurements in the near-field. The combination of the two methods leads to an accurate SSL in an interior enclosure in a more efficient way that has been done till now using masking techniques

1. Introduction

Engineers have been developing Sound Source Localization (SSL) techniques for the last ten years and industrial techniques now exit to measure in free field for example on engine testing bench and perform a SSL. Because of the free field conditions, these systems normally use a planar antenna. The data processing can combine acoustic holography for accurate low frequency analysis and near field Focusing for high frequency localization with a few number of microphones [1].

Measurements inside cabin involve additional challenges. Inside a cabin, the sources can be in front or behind the antenna. Secondly inside a cabin, there are reflective waves that can be identified as additional ghost sources. Inside cabins, the objective of a SSL system is to minimize the influence of the reflective waves and have a proper localization of the sources that are in front or behind the antenna. These two points avoid the use of a planar array which cannot separate properly sources behind and in front of the antenna.

This paper presents two dedicated solutions to respectively two types of analysis:

- **Measure of an entire space**. For an accurate localization of the 3-D acoustic field, MicrodB has developed (and patented) a spherical solid shaped antenna. This sphere can be placed on the one of the seats and provide a pressure map of the complete enclosed volume.
- **Measure of a limited zone of a volume**. In order to improve the spatial resolution it has been proved that the antenna should be closed to the surface that one wants to analyze. In this case, LMS-MicrodB has developed a half cylindrical antenna which is acoustically "transparent" which will give a better spatial resolution as the sphere but will only provide the results over a limited zone..

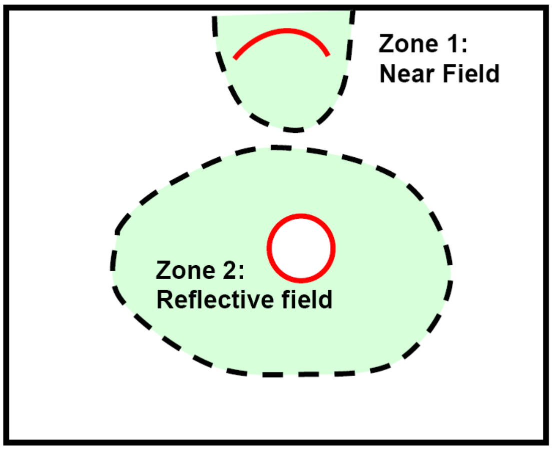


Figure 1: Two types of arrays/analysis

2. Spherical solid antenna

When working on interior acoustics in a cabin, it is not always obvious where the noise is coming from. So in a first instance it is interesting to have a tool which can visualize the sound pressure over a complete 3D volume. In order to be able to quantify a 3D sound field, LMS-MicrodB ahs designed a solid spherical antenna, which can be positioned in one of the front seats as can be seen in Figure 2.

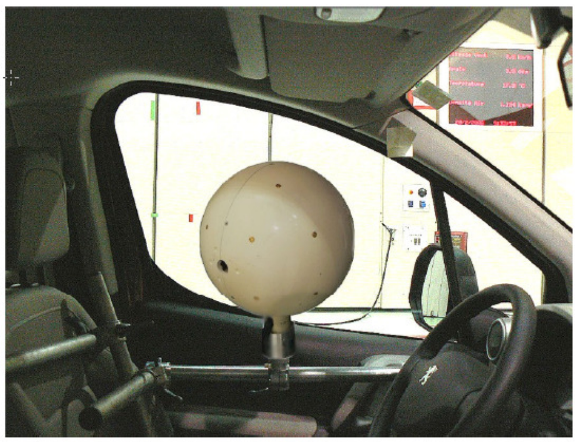


Figure 2: Spherical solid antenna

The advantage of the solid sphere is the capability to better separate the different microphone signals. MicrodB deposed a patent, in joint ownership with Airbus, on a process using a rigid antenna and a treatment of beam-forming to provide holograms

Figure 3 presents in a concrete way the influence of the solid sphere on the microphone signals. An acoustic source and two points on both sides of the sphere are considered. The curves represent the variation of level, for these two points, between the pressures measured with a solid sphere versus an open sphere.

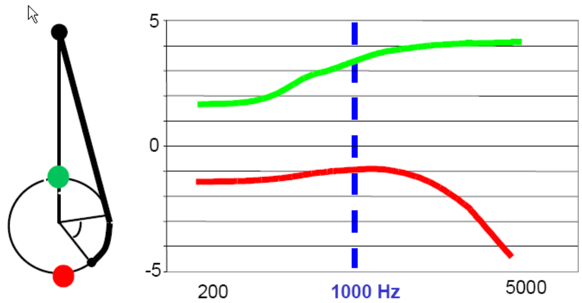


Figure 3: Diffraction between open versus solid sphere

The two main advantages of the solid sphere are:

- In low frequency, the level variation between two points in front of the sphere and behind is not very important (approximately 3 dB) but the phase between these two points increases because of the rigid body. The distance a wave has to travel is longer in case of a solid sphere versus an open sphere. This phase difference between the microphones improves the spatial resolution.
- For high frequencies, the solid sphere basically masks the sounds on the microphones that are laying on the opposite site of the sphere from where the sound is generated. As a consequence, the microphones which are laying at the opposite side of the calculation point are negligible. This improves the directivity of the sphere for higher frequencies.

The data processing for the solid sphere is modified to take account of diffraction. That is done with a decomposition on the spherical harmonics which can also be called spherical beam forming (or HRTF). For the transparent/open sphere, the treatment remains the traditional beam forming.

Figure 4 presents the resolution for a 23 cm diameter sphere located at 50 centimeters from the sources. The red curve corresponds to the resolution of a transparent sphere and the green curve of the rigid one.

The improvement in low frequency is about 40%. The acoustic holograms of a source located on the upper face of a virtual cube surrounding the sphere are presented for different frequency on the Figure 5, Figure 6 and Figure 7. The sphere diameter is noted a, and the cube volume is equal to $(10a)^{3}$. Figure 5 presents the results obtained for the open sphere and the solid sphere to a frequency such as k.a=2 with k the wave number. The green ring is 3 dB lower that the main source. One can easily observe the solid sphere provides a finer source localization than the open sphere.

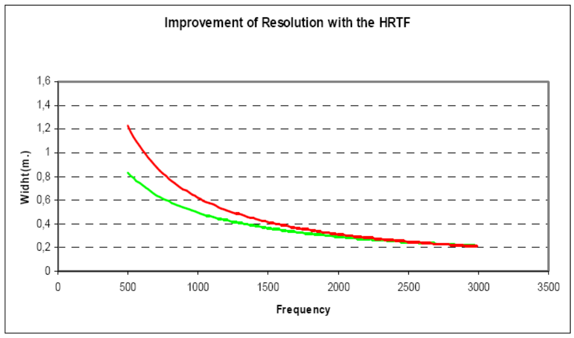
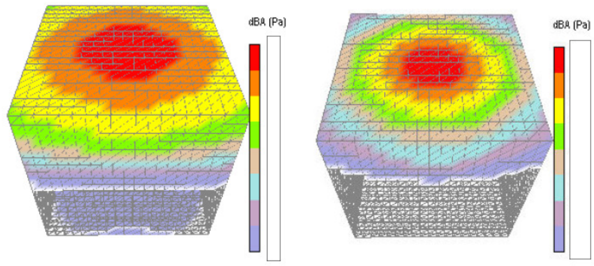
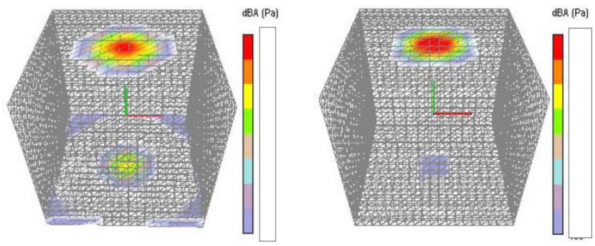


Figure 4: Resolution of the solid sphere ____ and the open sphere___



Open sphere Solid sphere

Figure 5: calculation with k.a=2 (dynamic 16dB)

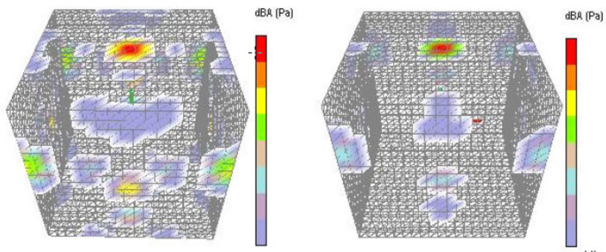


Open sphere Solid sphere

Figure 6: calculation with k.a=5 (dynamic 10 dB)

Figure 6 presents the results for a frequency k.a=5. We can note that ghost images are mainly located on the face opposed to the source. For the open sphere, the level of this ghost images is only 3 dB lower than the main source. For the solid sphere, the level of the ghost images is 8 dB below the main source giving the solid sphere a dynamic range of 8 dB.

Figure 7 presents the results for a frequency of k.a=10. In this case we can observe spatial under sampling of the acoustic wave.



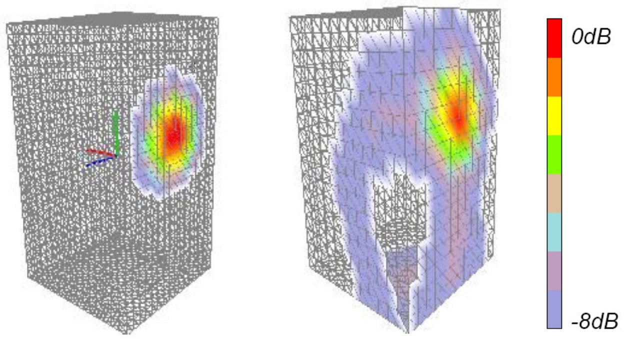
Open sphere Solid sphere

Figure 7: calculation with k.a=10 (dynamic 10 dB)

For the open sphere, we observe ghost images at -3dB on the face opposed to the source and at -4dB on the side faces.

With the solid sphere, all these ghost images are at least to -6 dB below the main source. Having a dynamic range of 6 dB or more is very important in performing a proper SSL.

The previous given provided results were for free field conditions. To find out the influence of being in a diffuse field versus a free field, the solid sphere was once place in a cube of roughly 15m by 1m by 1m that was acoustically treated providing a free-field condition. For the second measurement the acoustic material was remove from the cube giving a diffuse field. Figure 8 shows the results obtained for a frequency of k.a=4. For the free-field conditions, the dynamics range of the solid sphere is higher than 8 dB, whereas it is less than 6 dB in a diffuse field. In the examples described in Figure 5, Figure 6 and Figure 7 were executed in free field conditions. For these applications the open sphere had an inferior dynamic range than the solid sphere and was around 3 dB. Bringing the open sphere in an enclosure will only worsen this dynamic range.



Space with absorption Reflective space

Figure 8: measure with k.a=4 (dynamic 8 dB)

2. Half cylindrical antenna.

The advantage of the solid sphere is that one obtains a 3D pressure distribution of the interior and can localize the source very rapidly. However quiet often the distance to where the pressure is predicted is often 5 to 10 times the size of the sphere. A propagation to a larger distance from the sphere results in an image with less spatial resolution. This is inherent to beam-forming which is used during the calculations.

So in order to obtain a finer resolution, once the location of the source is known by using a solid sphere, a second measurement can be taken using a cylindrical antenna. The design of this antenna has been made such that the best spatial resolution if obtained for a zone in front to the antenna. This antenna should be placed close to the surface/source emitting noise. Even close to a surface the influence of the other sources present in the cavity and the reflective waves cannot be ignored. To minimize those effects, it is necessary to use a non planar antenna.

The half cylindrical array is the best compromise between the number of microphones and the localization accuracy. Indeed, for a given number of microphones this geometry allows covering a wide surface and as a matter of fact, improves the localization especially for low frequency. The picture below, shows the an 56 microphone cylindrical antenna applied to a door seal leak application.

Figure 9: Half cylindrical array

The array is designed to localize source in the frequency range from 500 to 4000 Hz. By placing the antenna in the near-field and using focalization instead of beam-forming a spatial resolution of 0.5λ is obtained. This is at least a factor to better than with beam-forming. However the 0.5λ spatial resolution might not be sufficient in the lower frequencies to make a proper engineering judgment.

On the obtained pressure maps for the lower frequencies, a second processing, called identification, can be done to improve the spatial resolution. This post-processing is based on the estimation of the monopole distribution that gives the holograms measured in real conditions. Consequently, it computes the inverse of the FRF (frequency response function) matrix between the back-propagated hologram and the simulated sources. The following expression of for one matrix element is: [2]

$$H(f) = \frac{1}{4\pi Rms} j\rho \frac{f}{c} e^{-j2\pi f Rms/c} \quad [\mathrm{kg/\,m^5}] \qquad (1)$$

Where:

- Rms is the distance in meters between a microphone and the simulated source
- ρ air density
- f frequency
- c sound of speed

Figure 10: Near-field focalization

This leads to a resolution improvement of a factor between 2 and 3 as it is shown in the figure below.

Figure 10 and Figure 11 presents the results for a frequency where D/λ=2, where D is the cylinder diameter. We can observe that the resolution improvement due to identification processing is very relevant

Figure 11: Identification

4. Conclusions.

This paper has presented two accurate solutions for sound source localization inside cabin.

A first patented solution is dedicated to localize the source distribution in one measure of an entire space by calculating the back-propagated acoustic field on a 3D mesh. This solution which uses a solid sphere with a spherical beam-forming processing appears clearly more accurate than the open sphere with classical beam-forming. A second system composed of a half cylindrical array and a combined processing of near field focusing + identification allows to localizes sources on a limited zone with the best performance we can expect in terms of resolution.

7. References

[1] Bernard BEGUET, Maxime ROBIN: "Combining acoustical imaging and identification techniques to localise and identify sound sources ", Automobile comfort conference SIA Le Mans nov. 2006.

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