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# Application examples of beamforming method

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Acoustical beamfoming technique is a powerful method for noise source investigation, suitable for many different situations. Thanks to this technology is possible to identify where the noise is coming from, in a very clear and understandable form, both in static on dynamic situation. In addition on standard features, some advanced functions can help to make correlation between subjective and objective parameters, for a better understanding of acoustic phenomena. This paper describes some real applications of a very innovative beamforming system, coming from measurements performed in several fields as automotive, enviromental noise, occupational noise, architectural acoustic, noise barrier design.

# 1 Introduction

In many situations is very important to detect, for a certain reciver, where the noise is coming from.

In order to achieve this goal some techinques are available, and one of the most powerful is without any doubt acoustical beamforming.

The main idea behind beamforming technique is to combine the signals coming from several non-directional microphones, in order to obtain a very directional sensor which can be 'electronically' oriented in any direction: this task is performed by introducing some position/frequency/direction dependent delays on signals coming from microphones, before summing all of them together. The process can carried out both in time or frequency domain and, although it requires a very big amount of calculation, it can be performed in very short time thanks to fast and faster PCs available today; moreover, if needed, with appropriate hardware everything can be done even in real-time, in order to analyse evolution of time variable acoustic phenomena.

Beamforming technique is not complicated at least in its basic principle; Fig 1 shows more in details what happens when a plane wave strikes a linear microphone array perpendicularly (top), with a certain angle (middle), and with the same angle but with appropriate phase delay added before sum (bottom). From the picture can be seen that, by adding proper delays, is possible to obtain in-phase response for any desired direction. Therefore, proper change of delays, results in virtually movement in a different direction of the 'virtual directional microphone' obtained as a combination of transducer.

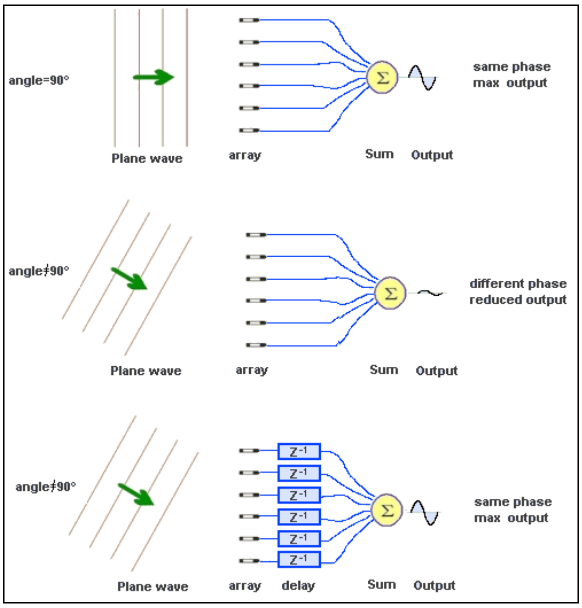

Fig. 1 Principle of technique

In a real beamforming transducer, microphones do not lie on a line as in the above simplified example, but are located on a plane or, as for the system used in the following measurements, on the space. More in detail, the transducer here described consists of 31 microphones located on the surface of a sphere, assembled together with 12 cameras in order to superimpose acoustic map obtained by interpolation of grid measurement, to the optical picture taken by the relevant camera. Thanks to this innovative configuration, is possible to analyse all the space around the transducer at the same time. Fig. 2 shows the complete system, which includes also front-end and PC. The showed system can be assembled and disassembled in few minutes, and can be successful used inside a car, as well as for environmental applications and more.

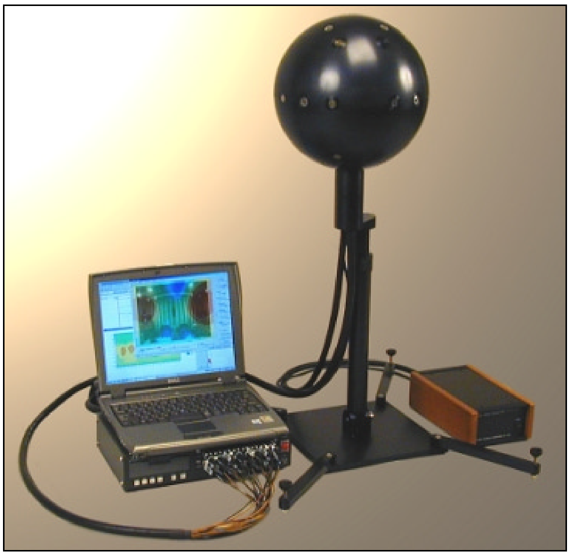

Fig. 2 System with spherical transducer

# 2 Measurements

Fig. 3 and Fig. 4 shows measurements inside a car in wind tunnel facility. In the pictures is possible to recognize different wind effects at different frequency bands. More in detail, in Fig. 3 shows the effect of the wind on the external mirror at 1250 Hz 1/3 octave band, while Fig. 4 shows the effect of the wind on pilar at 3150 Hz 1/3 octave band.

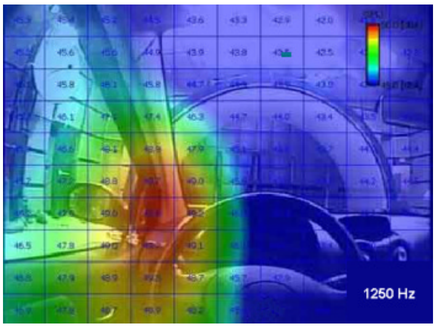

Fig. 3 Car in wind tunnel, 1250 Hz (courtesy of Pininfarina)

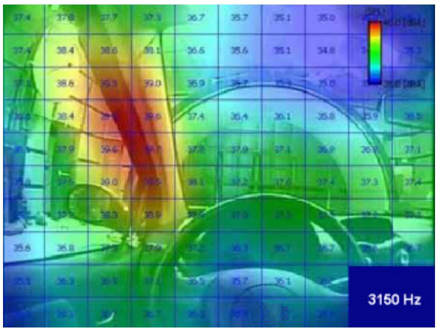

Fig. 4 Car in wind tunnel, 3150 Hz (courtesy of Pininfarina)

Fig. 5 and 6 shows building acoustic measurement, with a sound source inside a room, and the beamformer outside and close to the door. The first map shows 1000 Hz 1/1 octave band, while the second map shows 2000 Hz 1/1 octave band.

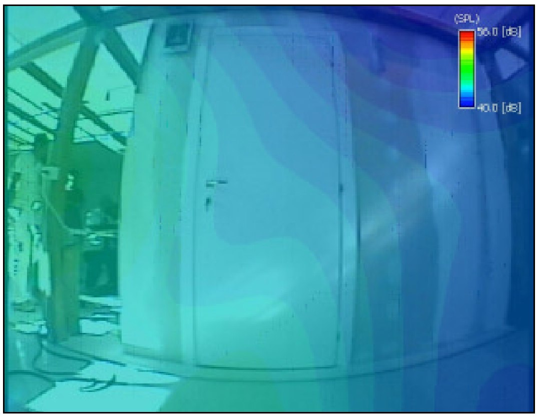

Fig. 5 Measurement close to a door a 1000 Hz

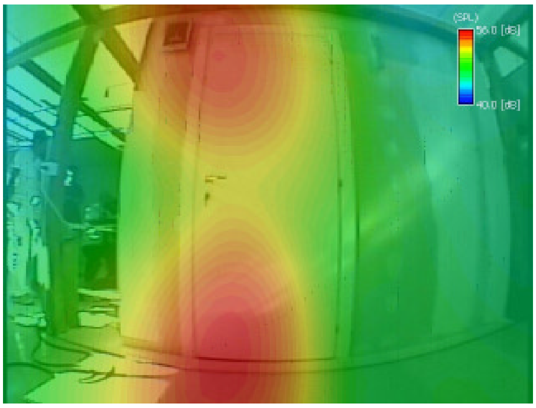

Fig. 6 Measurement close to a door a 2000 Hz

The physical reason for the two acoustic *piercing draught* can be seen in Fig. 7, in which is possible to recognize two small cables which pass thru the door sealing, that causes the above showed emissions.

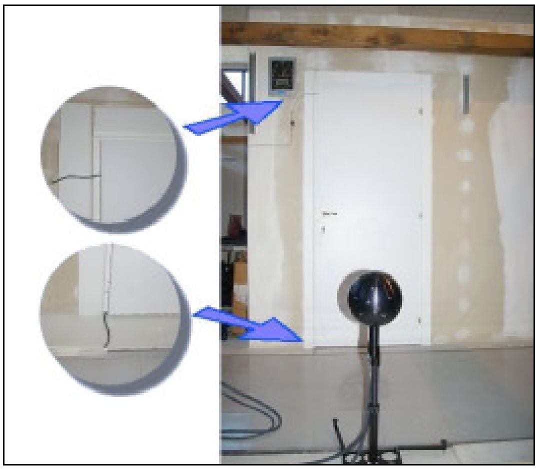

Fig. 7 Reason for emitted noise

Fig. 8 shows a measurement inside an office. In the image is clearly visible a problem at the conjunction between vertical partition and ceiling.

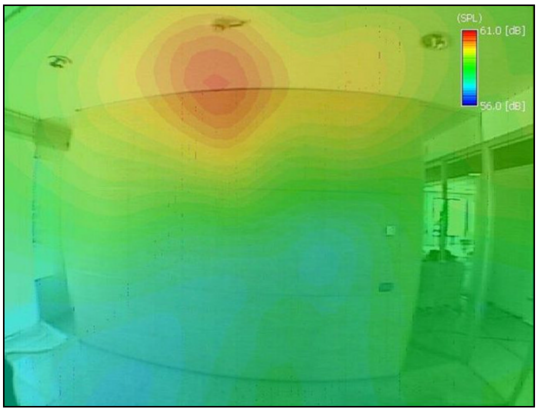

Fig. 8 Measurement inside office

Fig. 9 shows all the 12 cameras at the same time, in a measurement taken inside a listening room, where an omni directional sound source was placed. From the picture is possible to recognize reflections both on ceiling (more absorbing) and floor (less absorbing). The three green spots on ceiling are in fact related to the same reflection, which appears on more pictures because superimposition of viewed fields; the same for floor reflections.

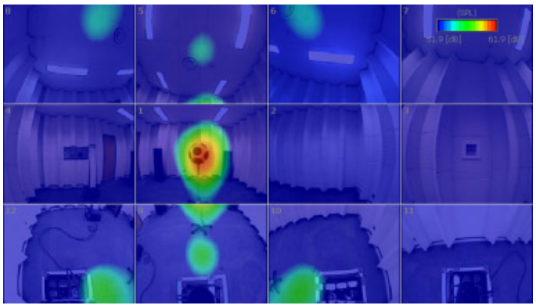

Fig. 9 Measurement inside a listening room

Fig. 10 represents a measurement inside an ancient cathedral, during an 800 people chorus. The measurement was taken in order to check some sound reflections. From the still image is possible to see how, at that moment, half all the people was singing (on the right), while the rest was not (on the left), but this is another story.

Fig. 10 Measurement inside ancient cathedral

Fig. 11 shows the transducer placed inside workplace, while Fig.12 shows how, for the considered position, most of the noise was coming from a ceiling reflection. In this case the system gave very clear information on what was necessary to do, in order to improve the noise environment.

Fig. 11 Measurement in a workplace

Fig. 12 Ceiling reflection at 1000 Hz

Fig. 13 shows a measurement taken outside the same factory, in order to understand where the noise was coming out. The image shows two cameras, and from the picture can be easily seen that, for the considered frequency, the main source was related with an air outlet placed outside the building.

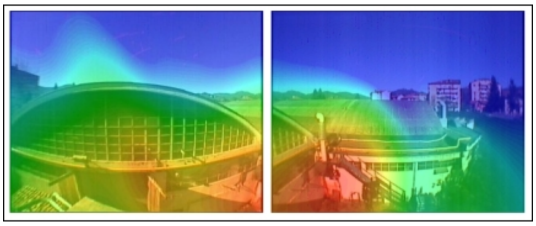

Fig. 13 Noise emission from a factory

Figure 14 shows a measurement on a hydraulic pump, performed in order to identify main source.

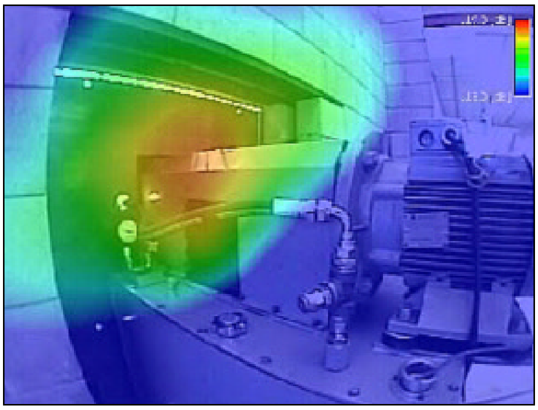

Fig. 14 Measurement on hydraulic pump

The system was also successfully tested for some noise barrier application. Fig. 15 shows the layout for a measurement performed to demonstrate the effect of the diffraction system.

Fig. 15 Measurement on noise barrier

The analyzed barrier has a portion of it with a diffraction system mounted on, and another portion without any crowning.

Fig. 16 Shows measurement with source in position S1 (behind the diffraction system), while Fig. 15 shows a measurement with source in position S3 (behind the portion without difractor). From pictures can be clearly seen the diffractor effect.

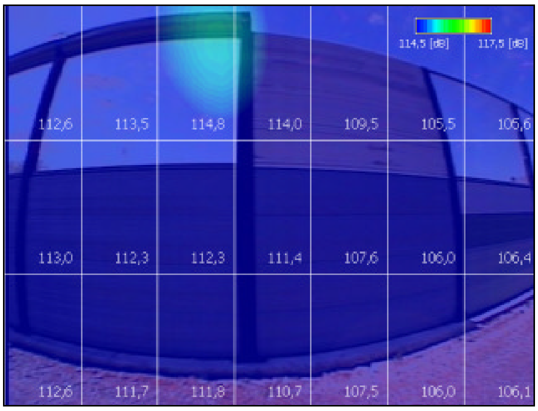

Fig. 16 Source behind diffractor

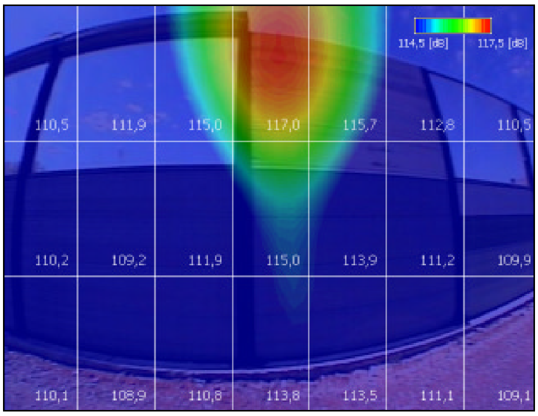

Fig. 17 Source behind the portion without diffractor

Next measurement was taken on a noise barrier over a viaduct. The first picture, Fig. 18, shows the effect of the end of the barrier, and the effect of the junction of the bridge in 1000 Hz 1/3 octave band.

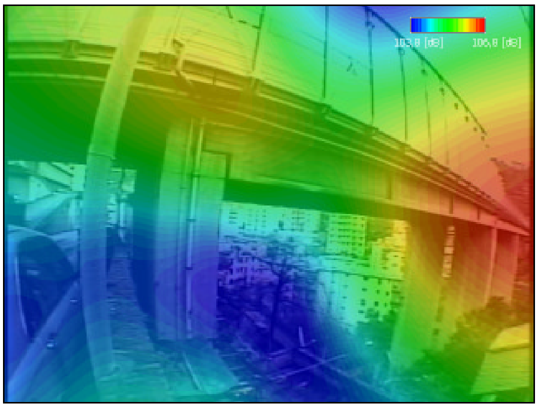

Fig. 18 Noise barrier over viaduct (1000 Hz)

Fig. 19 shows the same measurement for 1250 Hz 1/3 octave band. In this band is more visible the effect of the bridge junction.

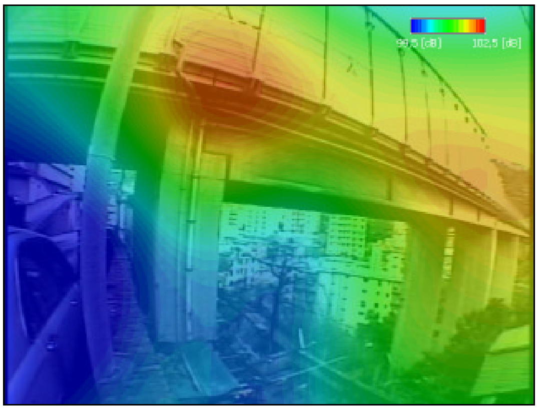

Fig. 19 Noise barrier over viaduct (1250 Hz)

Fig. 20 shows again the same measurement for 4000 Hz 1/3 octave band. In this band is possible to see the effect of a drainpipe

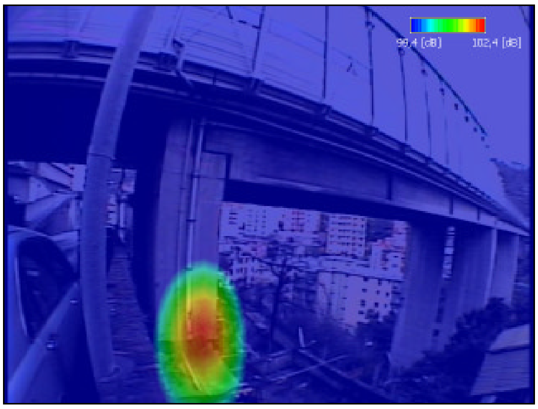

Fig. 20 Noise barrier over viaduct (4000 Hz)

Fig. 21 shows 5000 Hz 1/3 octave band. In the image can be seen again the effect of bridge junction, and another source not related with the viaduct.

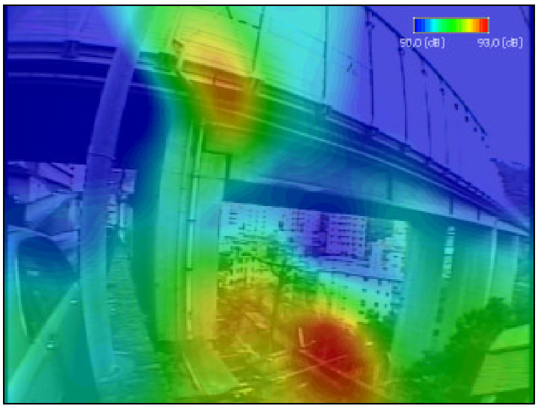

Fig. 21 Noise barrier over viaduct (5000 Hz)

# 3 Advanced analysis

In addition to standard noise mapping as above presented, some equipment can even perform other very sophisticated and powerful analysis. Next points will briefly discuss some of the special functions implemented in the system used for the above measurements.

## 3.1 Long term measurements

Due to full storage of all microphone channels, and thanks to the availability of high capacity hard disks, with the mentioned system is possible to store as much data as the hard disk can accept them. Therefore, some very particular and difficult-to-identify effect, e.g. rattle noise, can be successfully investigated with the system. In order to perform this kind of analysis is enough to continuously record data until the problem make its evidence, and then post process the portion of data where the problem is present.

## 3.2 Real-time analysis

In addition to analysis performed on recorder data, real time analysis can be conducted in order to obtain real time map during measurements. This feature helps a lot in all situations where some *adjustment* of the tested object should be repeatedly performed, as a function of the obtained results.

## 3.3 Order tracking

In many automotive applications, and in general in all those situation where the emitted noise is related with a rotating machine, could be very interesting and useful to have an ‘order scale’ instead of a ‘frequency scale’. This can be achieved by the meaning of a tacho transducer able to give rpm information to the system. In this case the analysis, which normally is performed in FFT or 1/n octave, can be conducted in terms of *orders*, thus it is possible to follow dynamic phenomena related with revolutions, as the noise emitted for a machinery during run-up or coast-down or, more in general, during a non-constant speed.

## 3.4 Directional hearing

Once calculation is done, a wave reconstruction for a given direction, both in narrowband or wideband, can be done, in order to have a subjective evaluation of the noise coming from that direction. With the described system this can be simply done by clicking the mouse in each part of the computed map. Therefore, thanks to this function, is very easy to selectively *listen* the noise related to a certain *spot* on the map.

# 4 Conclusions

Beamforming system is a very efficient tool for rapid identification of noise contribution coming from different directions for a given receiver. The technique can be successfully used to identify possible problems in many different fields; in the same way the beamforming technique can be a very powerful design tool, that can helps to optimize acoustic improvements by individuation of most critical points in the analyzed environment.

# References

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