24th INTERNATIONAL CONGRESS ON SOUND AND VIBRATION
23–27 July 2017, London

PASS-BY NOISE TESTS BY MEANS OF CIRA ACOUSTIC ANTENNAS SYSTEM

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In previous works, the system developed by CIRA's vibroacoustic Lab for pass-by-noise tests has been described. This system is made of a couple of synchronized acoustic antennas, with 96 analog MEMS microphones and one full HD camera for each antenna. The system developed in the national project LOWNOISE, funded by MIUR (Italian Ministry of Education, University and Research) has been used to perform a test campaign on the environmental noise of a FCA Giulietta equipped with two different kind of tyres: common ones and optimized ones (developed by FCA in LOWNOISE project). Tests have been performed in CIRA plant with different car speed starting from 20 kmh up to 50 kmh. These tests have shown the capability of the system to recognize and to separate correctly moving car noise sources, their spectral content and to verify the effectiveness in reducing the emitted noise of the optimized tyres respect to the common ones (a reduction of about 3dB and more has been assessed, with benefit increasing with increasing car speed).
Keywords: Beam-forming, Acoustic antenna, Acoustic source detection and localization

1. Introduction

In MIUR funded Lownoise project, CIRA had the task of developing an innovative system for environmental noise measurements during pass-by noise-test [1,2,3] based on acoustic antennas [4] and the beamforming technique [5] for signal processing. This paper describes the test activities carried out with the system described in [6] and [7] aimed at the characterization of external acoustic sources of a car travelling a road, with particular reference to the noise reduction achieved by the use of innovative tires.

The article describes tests carried out in the experimental campaign having as its goal to assess the effectiveness of the use of innovative tires for the abatement of environmental noise and the system's ability to locate and to track acoustic moving sources (this aspect will be presented in further works). Acoustic noise maps, power spectral density graph and the achieved goals in terms of dB noise reduction will be highlighted in this work.

2. System description

The system is composed of a pair of acoustic antennas with structure made in aluminium, for sake of weight reduction. The antenna surface for microphones integration is square with 1.5m side. The acoustic part of each antenna consists of 96 InvenSense analog MEMS microphones (model ICS 40720). Acoustic data are sampled at 96 kHz with 24-bit quantization. Data coming from each antenna are streamed to the acquisition system to a rate of about 600 Mbit/s through fiber optic cables.

Video are recorded with a FHD camera (1920 x 1280 maximum resolution) and streams data to the computer system (either in MJPEG or H264 format), over a RJ45 ethernet cable. Camera optics provides a FOV (Field-Of-View) maximum of 116° horizontally and 84° vertically. The workstation that allows contemporary video and acoustic data processing is a HP® ZBook 17 G2, with Intel® i7-4710MQ 2.5GHz quad core processor and Microsoft® Windows 7 operating system.

The algorithm implemented for acoustic antennas data analysis (the heart of the CIRA beamforming system) is a Filter-and-Sum beamforming algorithm, implemented in C programming language [8].

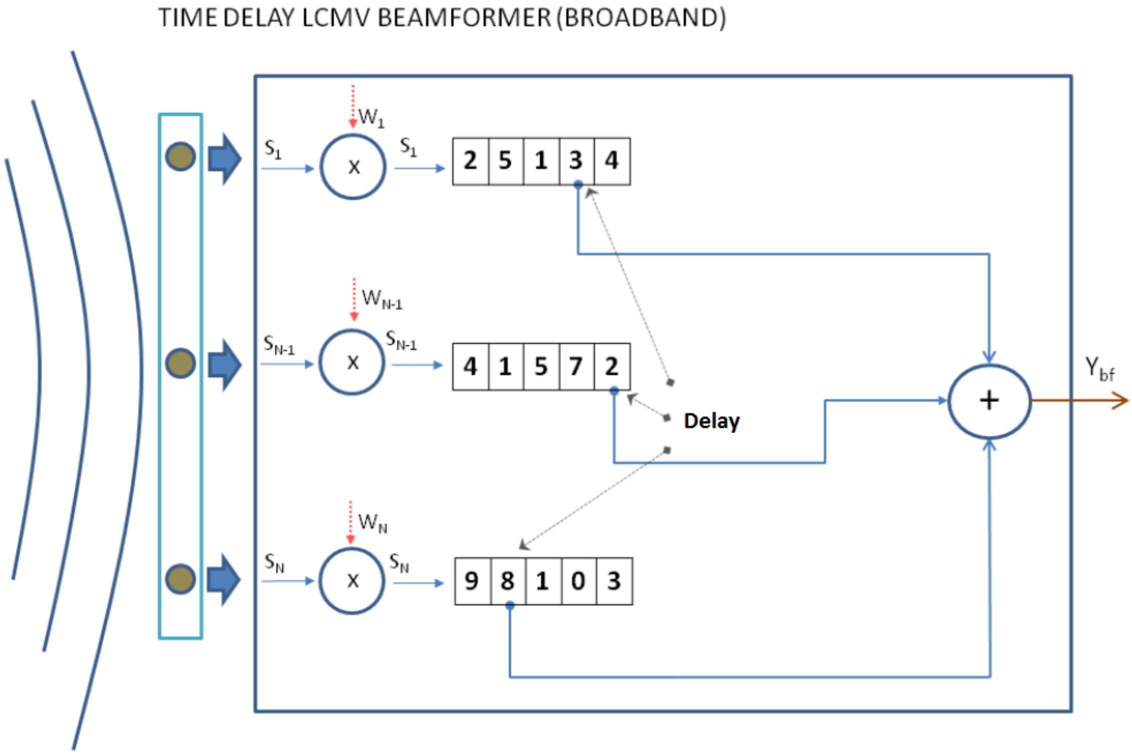

Figure 1: Beamforming algorithm for CIRA acoustic antennas.

The compiler used to implement the algorithm was the Gnu Compiler Collection (GCC). Optimizations (mainly vectorization) were introduced by using instructions specific for the machine and the compiler used. Parallelization, another feature introduced to speed-up the analysis and reaching a real-time implementation of the signal processing algorithm, was coded with OpenMP v4.0 C library (July 2013 version). By means of parallelization, a sequential code is converted into a multi-threaded code, where many calculations are carried out simultaneously by the threads on the different cores of the processing workstation. A speed-up factor close to the optimal of 32 comparing with a non vectorized and non-parallelized version was achieved. This allows an output of about 10 acoustic maps each second on a grid of 61x61 acoustic steering points.

3. Test description

The pass-by-noise tests were carried out at CIRA plant, using the available spaces of LISA (Aerospace Structures Impact Laboratory) facility. LISA is used for outdoor impact testing, with tests that can be performed on water, soft ground (grass) and concrete. Precisely this latter part of the plant has been used as a runway for pass-by-noise measurements (Fig. 2 - left). The track has a total length of about 105m and is about 24m wide (Fig. 2 - right).

Figure 2: Test Site for Pass-by-Noise test with CIRA acoustic antennas.

The car used for the tests was an Alfa Romeo Giulietta in test configuration provided by FCA (Fig. 3).

Figure 3: Test article for Pass-by-Noise test with CIRA acoustic antennas: FCA Alfa Rome Giulietta.

The car was equipped with two different kind of tyres: standard ones (Fig. 4) and optimized ones.

Figure 4: FCA Alfa Rome Giulietta: standard tyres

The tests were carried out during the pass-by of the vehicle between two CIRA acoustic antennas (15m spaced, see Fig. 5) at different stabilized cruise speeds: namely 20 km/h, 30 Km/h, 40 km/h and 50 Km/h (for the last case, however, a sufficiently stabilized cruise speed was not achieved due to the limited length of the track). Acoustic data were acquired and processed by means of two workstations that are part of the CIRA prototype acoustic antennas system (Fig. 6)

Figure 5: CIRA acoustic antennas

Figure 6: CIRA acoustic antennas data acquisition and processing system

4. Test results

4.1 Tests with standard tires

A first test campaign was carried out by mounting on the Giulietta standard tyres. The frequency range analysed is between 500 Hz and 2000 Hz (the range for which the antennas have been designed and where is concentrated the sound of some characteristics car noise sources, including tyres noise). Figures below show the noise maps related to the different cruise speed of the pass-by car with standard tyres mounted.

Figure 7: Pass-by-noise test with standard tyres: 20 km/h

Figure 8: Pass-by-noise test with standard tyres: 30 km/h

Figure 9: Pass-by-noise test with standard tyres: 40 km/h

From the figures it can be seen an increase in the overall noise emitted by the tyres with increasing driving speed.

It was also obtained, for the three pass-by speed specified before, the corresponding spectrogram in third octave bands (Fig. 10) for the frequency range of interest (500 Hz - 2 KHz)

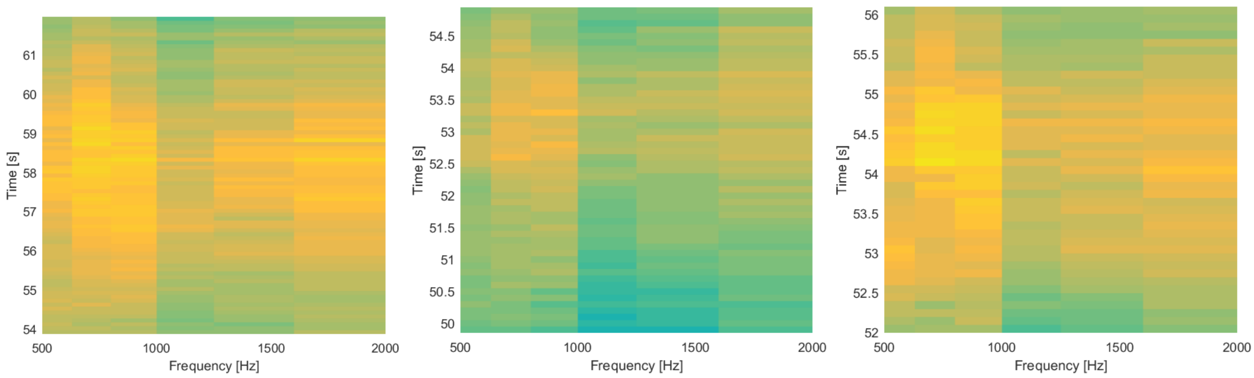

Figure 10: Pass-by test with standard tires spectrograms: 20 km/h (left), 30 km/h (middle), 40 km/h (right)

4.2 Tests with optimized tires

A second series of tests were carried out by mounting optimized tyres on the Giulietta. Measurements similar to those carried out with standard tires were made with this type of tires and led to the results shown in the following figures

Figure 11: Pass-by-noise test with optimized tyres: 20 km/h

Figure 12: Pass-by-noise test with optimized tyres: 30 km/h

Figure 13: Pass-by-noise test with optimized tyres: 40 km/h

Even for the pass-by tests with optimized tyres, spectrograms in the range of 500Hz-2000Hz were obtained (Fig. 14)

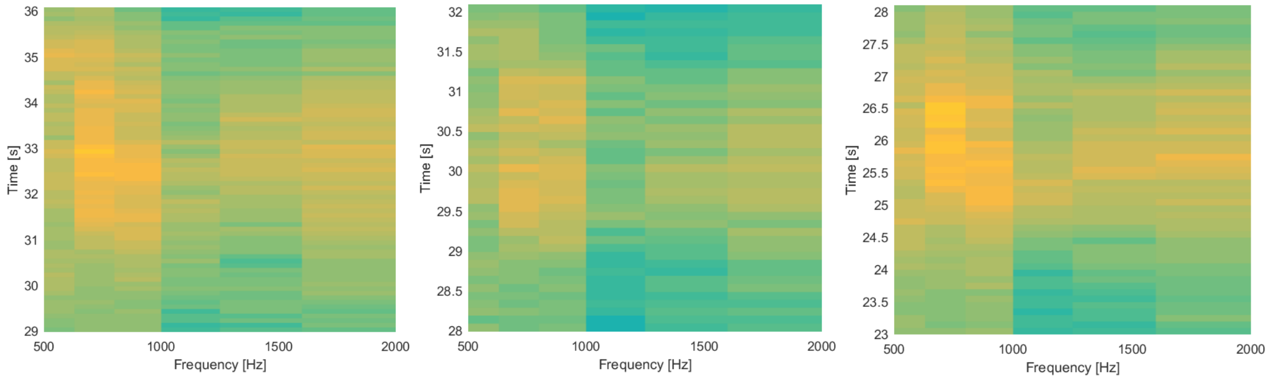

Figure 14: Pass-by test with optimized tyres spectrograms: 20 km/h (left), 30 km/h (middle), 40 km/h (right)

5. Standard vs optimized tyres comparisons

The values in dB of the noise emitted by the tires, in the frequency range 500Hz-2KHz, for various positions of the car in the measurement field and in particular for those positions for which the tyres were the main acoustic source, has been integrated suitably in order to obtain an average noise level. The values calculated for the standard and for optimized tyres were compared against. The noise reduction obtained with the optimized tyres are reported in the following table.

Table 1: Noise reduction between standard and optimized tyres

	20 km/h	**30 km/h**	**40 km/h**
	[dB]	[dB]	[dB]
Delta SPL ($SPL_{optimized}$ - $SPL_{standard}$) [500 - 2000] Hz	**+0,0**	**-1,0**	**-3,6**

The table shows the effectiveness of the optimized tyres compared with those not optimized. The noise reduction obtained increases up to exceed 3 dB for a driving speed of about 40 km/h and more for higher driving speed (the most common cruise speed for passenger cars is 50 km/h).

6. Conclusions

In the paper we have presented some of the results obtained during the pass-by-noise tests carried out with the innovative acoustic antennas system developed by CIRA vibroacoustic characterization laboratory. The tests showed the validity of the developed solution in the execution of pass-by-noise test with regard to the acquisition and processing of acoustic data in order to identify and characterize the main acoustic sources during environmental noise tests. In particular, the performed tests showed a reduction in the noise emitted by optimized tyres respect to the standard ones greater than 3 dB, in the 500Hz-2KHz frequency range for a vehicle speed equal to 40km/h.

ACKNOWLEDGMENTS

Authors want to thanks the Ministero dell'Istruzione, dell'Università e della Ricerca (MIUR) to have granted the LOWNOISE program in the Piano Operativo Nazionale (PON) 2007-2013 Project PON01_01878.

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