Application of a Wave Field Synthesis (WFS) Audio System based on A²B protocol: a case study

Antonella Bevilacqua[1]; Lamberto Tronchin[2]; Marco Binelli[1]; Lorenzo Chiesi[1]; Nicholas Rocchi[1]; Daniel Pinardi[1]; Andrea Toscani[1]; Angelo Farina[1]

[1] University of Parma, Italy
[2] University of Bologna, Italy
Corresponding authors: antonella.bevilacqua@unipr.it - lamberto.tronchin@unibo.it

ABSTRACT
Wave Field Synthesis (WFS) systems have been developed with the aim of controlling the sound field in a large area rather than in a single sweet spot, as it often happens for traditional solutions, such as stereo, Stereo Dipole or Ambisonics systems. This capability comes at the price of a much greater number of loudspeakers, which in turn usually makes these systems fixed installations, in listening rooms exclusively dedicated for this purpose. This paper describes the realization of a WFS system based on 8-channel soundbars, resulting in a more flexible, portable, and re-configurable solution, thus solving the previously described problems. The system is composed by 20 modules, for a total number of 160 loudspeakers, 20 meters length, and a capacity of 28 seats.

1. INTRODUCTION
In recent decades, spatial audio playback systems have been extensively studied due to the interest of increasing the immersivity of a variety of experiences, such as teleconferencing, video games for eSports, driving simulators, theme parks, or movies and home entertainment. This paper deals with the design and the installation of a WFS system [1], composed by 20 soundbars, each 1 m long and equipped with 8 loudspeakers. Each soundbar is provided with its own power supply and an 8-ch, class-D power amplifier. The audio signals are delivered to the power amplifiers through a digital bus developed by Analog Devices, the Automotive Audio Bus (A²B) [2]. Such solution provides several advantages: a huge dynamic range (thanks to the 24-bits resolution), a latency of just 2 samples (50 µs at 48 kHz), 32 synchronized signals on a single bus line with very small jitter [3]. Furthermore, thanks to the low cost of the A²B chips and the capability of carrying the signals over Unshielded Twisted Pairs (UTP), the cost of electronics and cabling is significantly reduced, especially if compared to analogue solutions, which require digital-to-analogue converters (DAC) and long power cables, or audio-over-IP solutions.

2. A²B SOUNDBARS FOR A WFS SYSTEM
A computer feeds the sound tracks of the WFS system through a RME MADIFace XT interface, capable of supporting up to 192 channels at 48 kHz on a USB3 connection. This soundcard provides three MADI interfaces, two optical and one coaxial. Each MADI interface carries 64 channels, and it is connected to a a purpose-built electronic board, named A²B-DSP, which delivers the audio signals to the power amplifiers over A²B. Each A²B-DSP board receives one MADI stream and feeds two A²B networks, carrying 32 signals each, which is currently the maximum number of channels supported on a single A²B bus. Finally, on every A²B bus four 8-channels active soundbars are connected in daisy-chain [4]. Since 20 soundbars have been built for this system, it will be possible in the future to expand the system with 4 additional soundbars, reaching the maximum capability of 192 channels.

The soundbars (Figures 1, 2, 3) are made of a birch wood frame and an aluminium plate on the back, for housing the power amplifier (based on the chip TAS3251), power supply (200 W) and connectors. Each soundbar has dimensions 100×19×14 cm (L×W×H) and a total weight of 10.5 Kg. Each of the 8 loudspeakers has its own separate volume of 1.2 litres. With the aim of reducing the standing waves inside the enclosures, they are partially filled with polyester fibre and the rear side of the frame is tilted by an angle of 10° for making the cavity not rectangular. The loudspeakers have an inter-axis distance of 125 mm, resulting in an aliasing frequency of 2.7 kHz (on-axis) and approximately 1.8 kHz at 30° [5]. The transducers are 4” full-range woofers by RCF, having a nominal impedance of 8 ohm and a sensitivity of 92 dB @ 1 W, 1 m.

Figure 1 – Front view of a WFS soundbar.

Figure 2 – Rear view of a WFS soundbar.

Figure 3 – Interiors of the electronics compartment.

Please note in figure 3, the “pass-through” power supply and A2B lines, allowing the sound bars to be easily daisy-chained with short and simple cables

A stress test was carried out to define the temperature profile of the soundbar (Figure 4). A white noise signal was played through a soundbar continuously for four hours at 100 W_{rms}. The temperature raised up to 62 °C against a room temperature of 26 °C. Then, the rear fan mounted in the electronics housing was switched on, and the temperature dropped to 42 °C in 1h 30’.

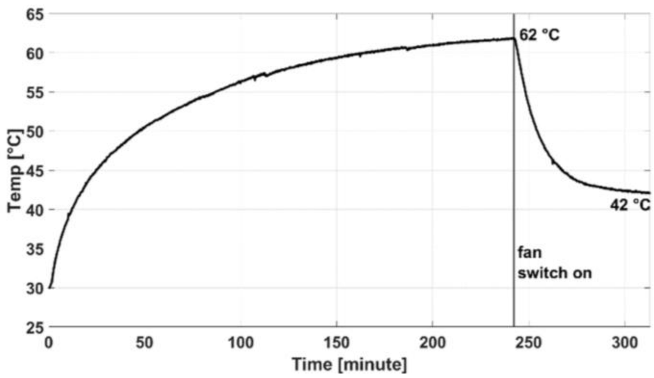

Figure 4 – Temperature profile of a soundbar as a function of time.

A test on the directivity was performed. The soundbar was mounted on a turntable controlled by a PC, in front of an omnidirectional measurement microphone (Bruel&Kjaer, type 4189) located at 1 m distance (Figure 5). An Exponential Sine Sweep (ESS) [6], was played through each loudspeaker, one at a time, for each measurement direction. A total number of 72 directions were measured, by rotating the soundbar with an angular resolution of 5˚, from 0˚ to 355˚. Finally, the impulse responses (IRs) were obtained, by means of the deconvolution with the inverse-ESS.

One of the eight resulting sets of polar patterns is shown in Figure 6.

Using advanced signal processing algorithms, namely Kirkeby matrix inversion, it is possible to calculate speaker equalization filters or synthesize a target directivity [7].

The digital equalization filter allows for a reasonably flat on-axis frequency response, as shown in Figure 7, and is implemented in real time as a FIR filter operated by the DSP units embedded in the A2B-DSP interface.

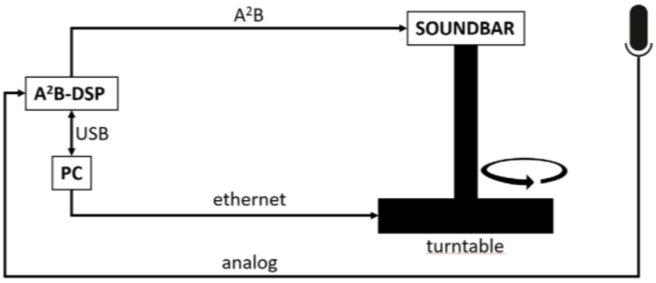

Figure 5 – Scheme of the directivity measurement.

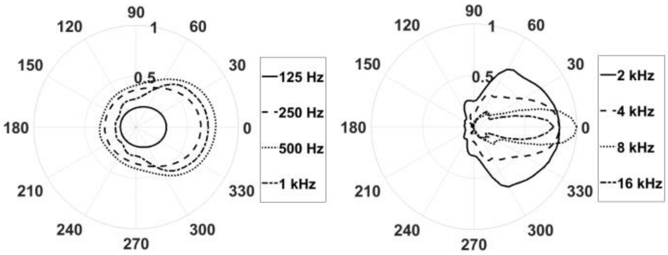

Figure 6 – polar patterns of a single loudspeaker.

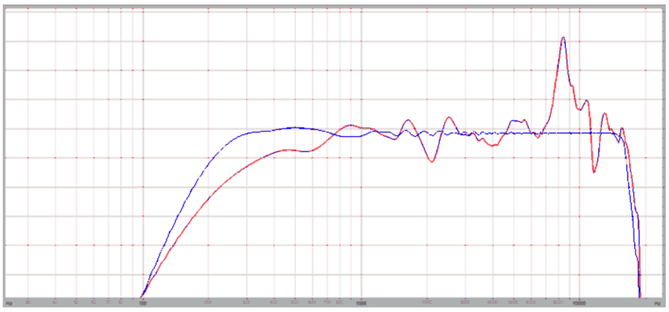

Figure 7 – On-axis anechoic frequency response without eq (red) and with eq (blue)

Finally, the maximum sound pressure level (SPL) produced by a soundbar was measured with an omnidirectional microphone (B&K 4189), located on-axis at 1 m distance. A value of 108 dB(A) was obtained, with all the 8 loudspeakers playing an 1 kHz pure tone at the maximum power.

3. GEOMETRICAL CONFIGURATION

The WFS system was assembled in a square configuration. By exploiting the modularity of the solution, corners have been tilted by 45°, thus significantly reducing the edge effects. The inner area of the system in its maximum configuration is 5.4×5.4 m, for a capacity up to 28 seats, as shown in Figure 8.

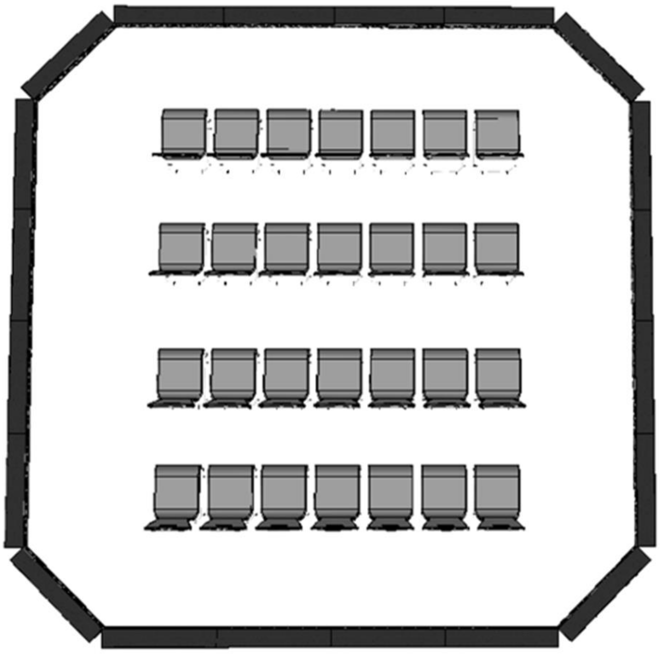

Figure 8 – Soundbars disposition for this case study.

16 of the 20 soundbars have been installed in the facility of the Bologna Creative Hub, Italy. A panoramic picture of the system, taken with a 360° camera, is shown in Figure 9.

Figure 9 – 360° view of the WFS system installed at Bologna Creative Hub.

4. SOFTWARE

For generating in real time the large number of signals necessary for feeding the WFS system, a novel software tool has been developed. It is a VST plugin, called WFSmixer, which allows to “spatialise” in real time up to 32 “sound objects”.

Each object can be placed in an arbitrary position, or it can be “animated” with a combination of translational and rotational motion units

The plugin, developed using Juce, has been compiled both for Windows-64 and Mac OS systems, and runs smoothly under multichannel host programs capable of high channel counts, such as Plogue Bidule or Max.

The plugin reads the geometry of the loudspeaker array from an human-readable XML file, containing the XY coordinates of the loudspeakers.

Figure 10 shows the GUI of the WFSmixer plugin.

Figure 10 – GUI of the WFSmixer plugin.

5. CONCLUSIONS

This paper deals with the realization of a modular, reconfigurable, and portable WFS system. Such characteristics have been reached by developing an 8-channel active soundbar and adopting the A^2B bus, which allows for connecting the modules in daisy-chain. Moreover, an A^2B, full-digital solution allowed for a considerably cost reduction.

The final installation was carried out in the facility of the Bologna Creative Hub, where the presented WFS system is now operating and available to composers and artists.

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