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A novel 32-speakers spherical source

Angelo Farina[1], Lorenzo Chiesi[2]

[1] University of Parma, Parma, Industrial Eng. Dept, 43124 ITALY
angelo.farina@unipr.it

[2] University of Parma, Parma, Industrial Eng. Dept, 43124 ITALY
lorenzo.chiesi@gmail.com

ABSTRACT

The construction and test of a novel compact spherical source equipped with 32 individually driven 2" loudspeakers is presented. The new sound source is designed for making room acoustics measurements, emulating the directivity pattern of various music instruments or human talkers and singers. The 32 signals feeding the loudspeakers can be obtained by three different approaches: a set of High Order Ambisonics coefficients computed for emulating the polar pattern of a fixed directivity source a set of SPS (Spatial PCM Sampling) signals recorded around a real source, employing a corresponding set of 32 microphones placed on a sphere surrounding the real source, a matrix of FIR filters, designed employing a mathematical theory almost identical to the one developed for creating virtual microphones from a spherical microphone array [1]

The presentation will show details of the construction of the new loudspeaker array, and the results of the first tests performed for evaluating the capability of creating arbitrary polar radiation patterns.

1. SPHERICAL LOUDSPEAKER ARRAYS

In the past very few attempts were done in building spherical loudspeaker arrays capable of creating arbitrary emission patterns. The most remarkable one was certainly the 120-loudspeakers spherical source built at CNMAT by Adrian Freed and colleagues [2], which employs special drivers (Meyer Sound) capable of very good low frequency emission despite the small size, and advanced electronics embedded inside the sphere.

This source was designed specifically for being able to create the complex polar patterns required by High Order Ambisonics, which of course require a lot of transducers for being able to generate directivities characterized by severe spatial variations over small angles (high spatial gradient).

Some other authors attempted to use a standard dodecahedron, driving separately the 12 drivers, but in this case, oppositely, the number of transducers revealed to be too small, and hence the capability of creating complex polar pattern has not been attained [3].

Our approach is intermediate between these two extremes: we designed and built a spherical source employing 32 2” drivers usually employed in linear arrays, so that the hardware is low cost and easy to find. The size of the sphere is as much compact as the size of the drivers allowed, creating a very small source, which can therefore operate with good directivity control up to 4-5 kHz.

Bamboo wood was employed for the spherical shell, thanks to its peculiar properties of small weight and great rigidity.

The goal for this source is not to be able to create higher orders spherical harmonics patterns, as the main usage planned for it is with our new SPS (Spatial PCM Sampling) method [4,5].

The chosen hardware revealed perfect for this task, albeit when used with HOA methodology our source suffers of some spatial aliasing problems at high frequency and for high order harmonics, making it usable in full range just for 2nd order Ambisonics, and within a more limited frequency range for 3rd order Ambisonics.

2. THE HARDWARE

The chosen driver was the RCF 2” wideband unit model MB2N101 (6 Ohm). This unit has the following free-field response at 1m, 1W:

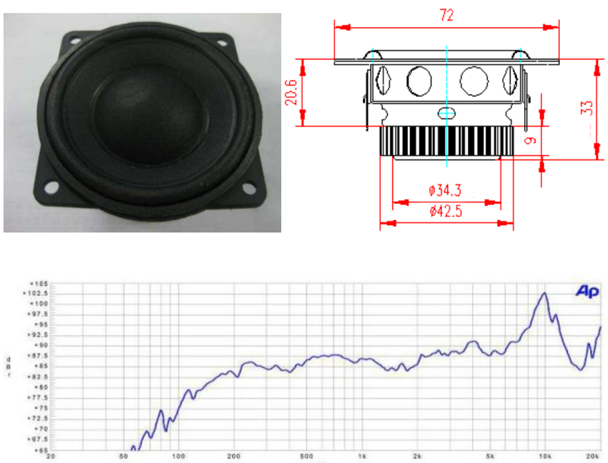

Figure 1 - the RCF 2” driver and its frequency response

It must be noted that at high frequency this loudspeaker has a peak on-axis, caused by a severe beaming problem. But this occurs around 10 kHz, and our spherical source is optimized for working up to 6 kHz (4 kHz octave band), so this is of minor concern.

Below 200 Hz the driver has a weak free field response, but at low frequency most sources are almost omnidirectional, so here all the 32 drivers will cooperate together, providing good power at low frequency.

This means that the source will be usable in the whole frequency range of the octave bands 125 Hz to 4 kHz, normally employed.

The following figures show how the spherical body of this sound source was built.

First two Bamboo-wood bowls were purchased from Ikea, and glued together by means of wood spacers, so that they are perfectly inscribed in a sphere having a diameter of 200 mm:

Figure 2 - the Ikea Bamboo bowls

Then the sphere was scraped, removing the extruding part of the wood spacers. And finally 32 holes were drilled, at position corresponding to the centers of the faces of a truncated icosahedron:

Figure 3 - drilling the 32 holes

A central aluminum rod was inserted, allowing for the passage of the 32 wire pairs, which also works as mechanical support for the sphere:

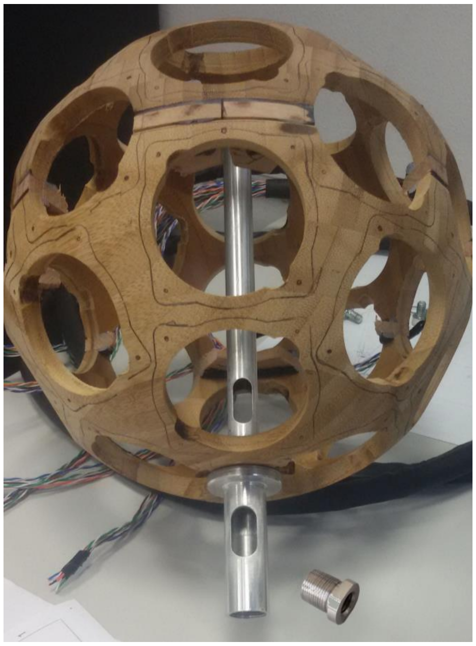

Figure 4 - the complete wood body of the sound source

Finally, the sphere was painted black, the 32 drivers were screwed in position, correctly wired and sound absorbing foam was placed inside the body:

Figure 5 - final assembly of the drivers

The finished product is remarkably compact (total diameter 200mm) and light (total weight less than 3 kg, thanks to the neodymium loudspeakers:

Figure 6 - the complete spherical source

It must be noticed that these small loudspeakers are indeed very powerful, as each of them is rated for a 30 W RMS continuous power with white noise. Hence the total power of this compact source is close to 1000 W RMS!

The problem, of course, is that the surface is limited, hence this power cannot be easily dissipated: running the source at full power for more than a few seconds will inevitably cause overheating.

For driving the 32 individual loudspeakers with proper power, avoiding clipping, a bank of powerful amplifiers is needed. In our case, we did employ a rack containing 4 QSC CX-168 8-channels amplifiers, which can output approximately 110 W over a load of 6 Ohm, which is plenty enough for driving each loudspeaker at its full rated RMS power avoiding any risk of clipping the signal over the amplifier.

Finally, the 32 independent signals are generated by means of an Antelope Audio Orion interface, which is interfaced with the computer by means of an USB-2 cable.

Figure 7 - amplifiers and USB interface, 32 channels

The first tests performed feeding all 32 loudspeakers with the same signal (pink noise), with 10 dB crest factor and peaks arriving at -6 dB from the clipping limit of the amplifier, resulted in a total acoustical power level, Lw, measured according to ISO 9614-3 standard, equal to 122 dB, which is larger than most dodecahedron loudspeakers of bigger size currently employed for room acoustics measurements. This means that this source is suitable for performing measurements also in large halls, such as large auditoriums or theaters, guaranteeing a good S/N ratio.

3. USAGE

The source can employed in three different ways:

1) As a traditional omnidirectional source by feeding exactly the same mono test signal (typically an Exponential Sine Sweep) to all 32 drivers

2) As a source beamformer, feeding it with a single mono test signal convolved with a vector of 32 FIR filters, designed in such a way that the radiated sound field is characterized by the prescribed directivity pattern

3) As a virtual reality source, feeding it with a 32-channels anechoic recording of a musical instrument, obtained placing 32 measurement grade microphones over a sphere surrounding the instrument, inside an anechoic room. In this case, a 32x32 FIR filter matrix is required, for beamforming each input signal in the corresponding directive loudspeaker firing the sound wave towards the same direction where the corresponding microphone was located during the anechoic recording.

At the time of writing, only experiments with method 1) have been performed. But it is planned that during the oral presentation of this E-brief, also results obtained with methods 2) and 3) will be available.

The following figure shows the experimental verification of the omnidirectionality obtained, measured over a turntable inside an anechoic room:

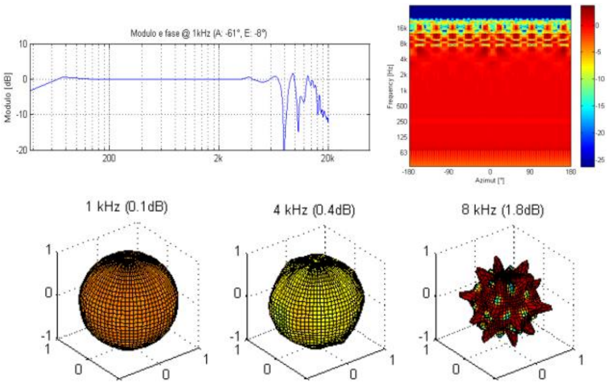

Figure 8 - verification of omnidirectional radiation

As shown in fig. 8, the source is perfectly omnidirectional up to 5 kHz, and exhibit beaming only in the 8 kHz octave band.

4. BEAMFORMING FILTERS

For creating radiation patterns of arbitrary shape, a set of beamforming filters is required. The numerical approach employed for building the sets of FIR filtering coefficients employed is basically the same that we did already develop for microphone array, with the goal of synthesize “virtual microphones” of arbitrary shape [1].

Similarly to what described for microphone arrays, it is possible to define the following processing system capable of generating driving signals for S loudspeakers from the signals of W virtual sources with arbitrarily defined directivity.

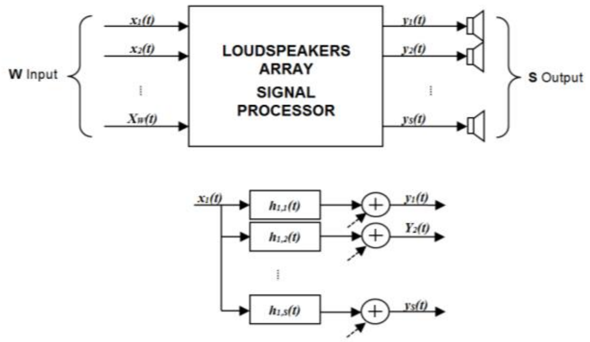

Figure 9 - Scheme of the speakers array signal processor

$$y_s(t) = \sum_{w=1}^{W} x_w(t) * h_{w,s}(t) \tag{1}$$

In this case it is required to measure the impulse response of each loudspeaker towards each of the D directions, defining a column of the matrix *C* of size *D*x*S*. Considering a 32-speakers array, the optimal number of directions D was found to be equal to 362, uniformly distributed over the surface of a sphere.

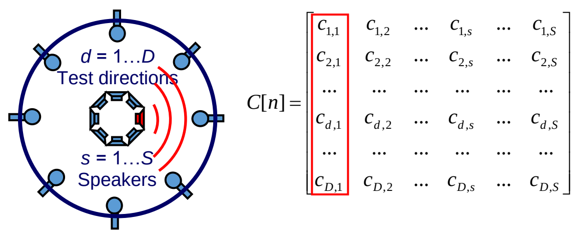

Figure 10: Speakers array characterization

For each of the W virtual sources to be synthesized, the matrix of the target directivity *Q*, with dimensions *D*x*W*, has to be defined.
It is therefore possible to define the following equations system, which is converted to frequency domain for transforming convolutions in simple multiplications:

$$\underset{D\times S}{\|C[n]\|} * \underset{S\times W}{\|H[n]\|} = \underset{D\times W}{\|Q\|} \cdot \delta[n] \overset{DFT}{\Rightarrow} \underset{D\times M}{\|C[k]\|} \cdot \underset{M\times V}{\|H[k]\|} = \underset{D\times V}{\|Q\|} \tag{2}$$

This system does not allow for an exact solution. However, a least-squares approximation of the solution can be found, employing the Kirkeby regularization (an extension of the Tikhonov regularization to MIMO systems):

$$\underset{S\times W}{\|H[k]\|} = \frac{\underset{S\times D}{\|C[k]\|^*} \cdot \underset{D\times W}{\|Q\|} \cdot e^{-j\pi k}}{\underset{S\times D}{\|C[k]\|^*} \cdot \underset{D\times S}{\|C[k]\|} + \beta[k] \cdot \underset{S\times S}{\|I\|}} \tag{3}$$

The frequency-dependent regularization parameter *β[k]* is usually set at a small value inside the optimally-conditioned frequency range for the array (80 Hz to 5 kHz, in our case), and at a progressively larger value outside this range:

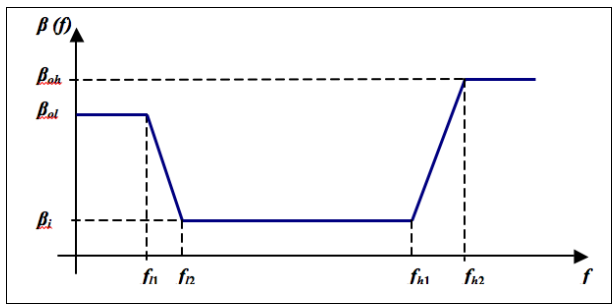

Figure 11 - regularization parameter in dependence of the frequency

In practice, the loudspeaker array should be characterized placing it inside an anechoic room, installed on a two-axis turntable, and rotated in 362 different directions. For each position of the array, the 32 impulse responses from each driver to the microphone have to be measured. This makes the measurement procedure much longer than the one employed for microphone arrays, because now 32 subsequent sweeps need to be played for every loudspeaker position.

5. CONCLUSIONS

A compact, lightweight and powerful 32-speakers array was designed, built and tested. This new sound source is ideally suited for measuring room impulse responses in rooms, associated with a 32-capsules spherical microphone array, allowing for a the measurement of a complete spatial-MIMO impulse response matrix for each pair of positions of source and microphone.

The resulting IR matrix will be 32x32 in case of using the SPS format, and 16x16 in case of using the old High Order Ambisonics format limited to orders up to 3rd.

The source can also be employed as a traditional omnidirectional source, providing better omnidirectionality and very good power over an extended frequency range, outperforming dodecahedrons currently in use.

Finally, the source can also be employed for playing musical recordings, sampled with a microphone array surrounding the source, and in this case the time-variant directionality of a musical instrument (for example a violin) can be captured and replicated, creating a perfect illusion that a real violin is playing on stage.

6. ACKNOWLEDGEMENTS

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This paper is dedicated as a tribute to Alberto Amendola, one of the inspirators of the work conducted at the University of Parma on transducer arrays, and co-author of many papers on this topic, who sadly and prematurely passed away in March 2016. He was also an excellent piano tuner, and we miss his incredible sensitivity to subtle sonic effects, together with his exceptional human qualities.

7. REFERENCES

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