Controlled illumination by DDS-driven (cardioid) loudspeaker arrays

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Introduction

After the introduction of Digital Directivity Synthesis (DDS) three years ago[1], AXYS DDS-driven arrays (like the Target and Intellivox-XL series) have been successfully applied during many music performances (front-of-house system) and also in a few fixed installs (PA and voice evacuation).

Using DDS, which is based on a 'constrained least squares' optimization scheme, any desired 3D array response can be synthesized. Starting from a pre-defined array set-up and desired SPL distribution at the boundaries (including the audience area) of a (fictive) hall, the optimum output filters for the array elements (channels) can be calculated. Next, these output filters can be uploaded to all units in the array.

In this paper the design, optimisation and testing of an active, DDS-controlled, cardioid Intellivox loudspeaker array is presented. The array is driven in such a way that a strong directional behaviour in the vertical plane and a cardioid-like behaviour in the horizontal plane is obtained over a large frequency range.

The proposed optimisation technique can be applied to other array types as well (e.g. bass arrays). Due to their 'unidirectional' behaviour these cardioid loudspeaker arrays are expected to have many acoustic benefits[2]; noise control, improved indoor bass response, higher direct-to-reverberant ratio, higher gain-before-feedback, improved echo-reduction in delayed set-ups, etc.

DDS-optimised cardioid-like arrays

In order to combine the effect of a vertical line array (high vertical directivity) and the large front to back ratio of a cardioid source, a cardioid Intellivox loudspeaker array was built and tested. Such an array is expected to show a strong directional behaviour in the vertical plane and a cardioid-like behaviour in the horizontal plane for low and mid frequencies.

Using the DDA (Digital Directivity Analysis) software, it is fairly easy to optimise output filters for a cardioid array. First, a suitable array set-up was defined. Secondly, appropriate values for the desired response at the boundaries of a fictive hall were defined. Starting from this pre-defined array set-up, the optimum output filters for the array elements were calculated by the DDS-algorithm.

Cardioid array set-up

The array, which was used during the test, consisted of two Intellivox-2c-XL columns (acoustic length approx. 2 m), assembled back-to-back. Each column has 16 loudspeakers, driven with 8 channels. In contrast to the standard DDC Intellivox-2c columns, this XL-version can be DDS-optimised. The distance between the fronts of the cabinets was 150 mm.

Simulations

In DDA the realised SPL distribution of the optimised array can be calculated. As an example the response at 250 Hz is shown in Figure 1.

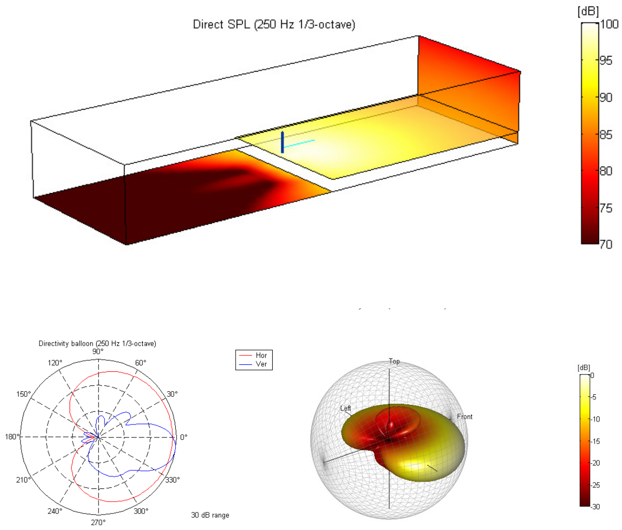

Figure 1: Simulated SPL distribution, horizontal and vertical polar pattern, and the 3D balloon of the cardioid 2x Intellivox-2c-XL array.

The simulation results in Figure 1 show that this cardioid array exhibits a strong directional behaviour in the vertical plane and a cardioid-like behaviour in the horizontal plane.
With DDA it can be verified that using the cardioid set-up the maximum continuous SPL in the audience plane for low frequencies is approx. 5 dB higher than for the single array. Note that adding a coherent array would result in a 6 dB increase. This means that the sensitivity of the total array is very well controlled.

Measurements

In order to verify the simulated response, outdoor measurements were done on the cardioid test array. The array was vertically flown into a scaffold positioned on a grass field. The lowest loudspeaker was raised to a height of 3 m. A number of 19 measurement positions were defined along a semi-circle with a radius of 15 m at 10-degree intervals from the front to the back of the array. At each receiver position a TDS measurement was done using a TEF20 system. The height of the microphone was 1.6 m.
The time window was chosen such that reflections from buildings in the vicinity were eliminated. However, in order to maintain a sufficiently high frequency resolution (25 Hz),

this time window was still too long to eliminate the ground reflection. It was assumed that for low and mid frequencies the ground reflection had a similar effect to the measurement results at all angles. Therefore, no correction was necessary.
First, the double Intellivox array was driven as a cardioid array. Secondly, for comparison, the array was uploaded with a single array setting (only one Intellivox active).
Since the measurements were taken outside, the noise conditions were quite poor for low frequencies (below 250 Hz). Especially at the backside of the cardioid, the results were affected by the background noise.

Results

A part of the 1/3-octave averaged measurement results are shown in Figure 2 for the single as well as the cardioid array set-up. For visualisation reasons, the results from 0-180° are mirrored to 180-360°. Using DDA, the results are also simulated at the same positions as during the measurements.

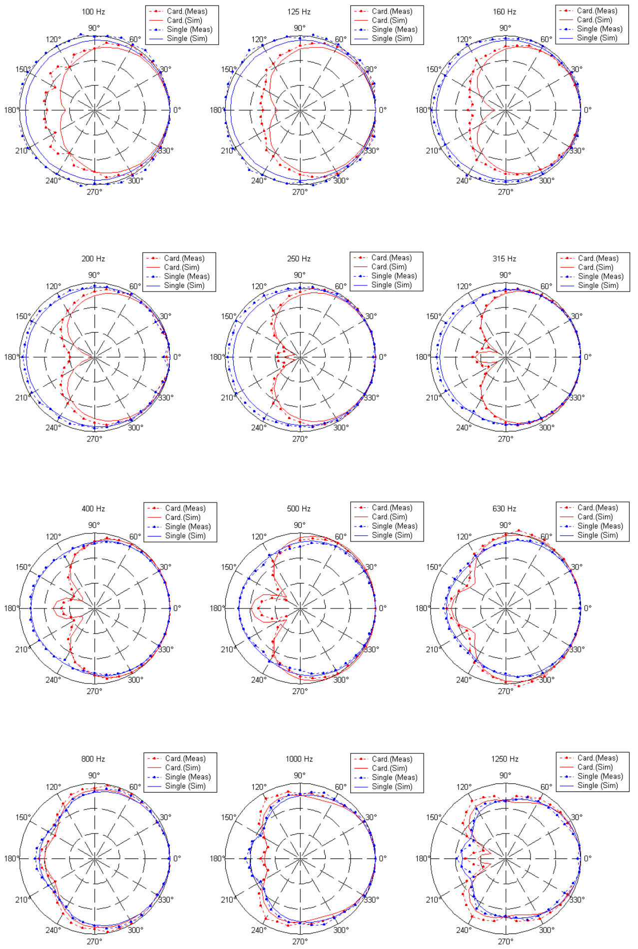

Figure 2: Measured and simulated 1/3-octave 'polar' diagrams (100-1250 Hz) for the single and the cardioid array set-up (10 dB/div)..

The results show that the cardioid-optimised array has a strong rejection to the rear over a large frequency range. For low and mid frequencies (below 630 Hz), an extra (i.e., compared to the single array) reduction of up to 20 dB can be realised. The maximum reduction is not always found at 180°, but shifts towards the sides (tendency to hypercardioid behaviour).
There is a good overall agreement between measured and simulated data. Due to the poor LF signal-to-noise ratio at the back, the simulated attenuation at those angles couldn't be verified.
For higher frequencies (above 630 Hz) the horizontal directivity pattern of the array is mainly determined by the directivity of the single array.

Conclusions

The AXYS, DDS technology has been applied to optimise an active cardioid loudspeaker array consisting of two separate Intellivox-2c-XL columns. The tested array set-up shows a strong directional behaviour in the vertical plane and a cardioid-like behaviour in the horizontal plane over a large frequency range. A backward rejection up to 20 dB can be realised.
The proposed approach has the following benefits:

- Generic concept. The DDS technique can be applied to arbitrary array configurations (e.g., bass arrays).
- Modular array set-up. A single array can be 'upgraded' if necessary to a cardioid array by adding a unit to the back.
- Radiation pattern can be fully customised by software (DDA).
- Automatic sensitivity optimisation. In the DDS algorithm the sensitivity is optimised in combination with the radiation pattern.

Future research will be focussed on a more efficient physical implementation of the cardioid array. Since the loudspeakers in the rear of the array are mainly active at low and mid frequencies, it is expected that a sparser loudspeaker distribution can be used without degrading the overall performance.

References

[1] G.W.J. van Beuningen & E.W. Start, Optimizing directivity properties of DSP-controlled loudspeaker arrays. Proceedings of the Institute of Acoustics (Reproduced sound) Vol 22 part 6 (2000), p 17-37

[2] L.L. Beranek. Acoustics (McGraw-Hill, New York, 1954).

[3] M.M. Boone & O. Ouweltjes. Design of a loudspeaker system with a low-frequency cardioidlike radiation pattern. J. Audio Eng. Soc., Vol. 45, No. 9, 1997.