AXYS® DDC

Some notes on modeling the directivity of DSP controlled loudspeaker arrays

by Gerald van Beuningen

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1. Introduction.

This report describes some aspects regarding the directivity modeling of the AXYS® Intellivox range of DSP controlled loudspeaker arrays.

In general accurate directivity information of a source is required in order to predict the behavior of a source in a room. An acoustical prediction software package usually describes this directivity with a directivity 'balloon' representing the magnitude of the sound pressure as a function of a horizontal and vertical radiation angle. Because it is time consuming to make a full spherical measurement of the directivity of real-life sources, this 'balloon' is usually constructed from measured horizontal and vertical polar data by using some kind of interpolation algorithm. For most sources the directivity is also depending on the frequency. Therefor a set of 'balloons' is constructed from frequency dependent polar data. To reduce the data storage requirements (and associated computation times) a limited set of frequencies is chosen. The polar data is usually averaged within a specific frequency band around these center frequencies.

The Intellivox range of loudspeaker arrays are capable of generating a very narrow vertical radiation pattern resulting in far-field opening angles (-6 dB) of a few degrees. As a consequence this puts constraints on the modeling of the vertical directivity of loudspeaker arrays with respect to the angular resolution. A probably even more important, and often overlooked, effect of long line-arrays is an increased near-field range. In the near-field the vertical directivity is depending on the measuring distance. Modeling the directivity as a fixed, distance independent, balloon may result in severe errors as we shall see in the next sections.

2. Angular resolution.

Modeling the directivity of complex sources can be inaccurate if the angular resolution is too low [1]. We will show here that the de-facto resolution of 10° is insufficient for long loudspeaker arrays.

Consider the setup for a vertical polar measurement as schematically shown in Fig 1.

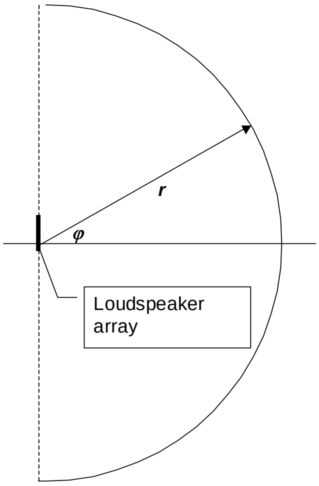

Fig 1 Setup for vertical polar measurement.

In this figure a side view of the loudspeaker array is shown. The measuring distance is represented by ***r*** and φ is the vertical angle of the polar measurement (if $\varphi = 0°$ the measurement is 'on axis').

The blue curve in Fig 2 shows measured polar data for a 16 element loudspeaker array generating two main lobes (equipped with 'dual lobe' DSP software). A main- and a second lobe are generated at $\varphi = -5°$ and +5°. Note that carthesian in stead of polar coordinates are used to represent the polar data from -90° to +90°. It is obvious that, even for octave averaged data, the errors are severe if a fixed angular resolution of 10° is used (red curve).

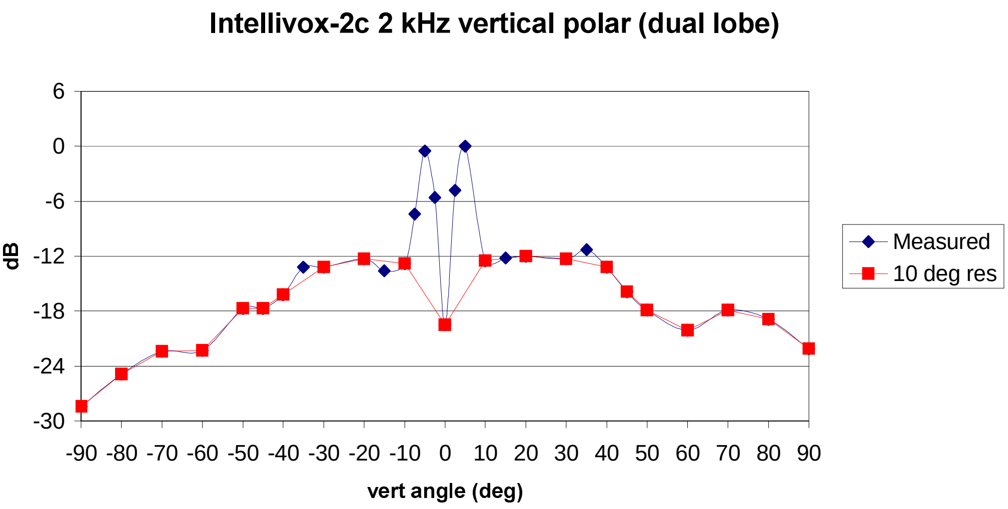

Fig 2 Octave averaged vertical polar of a loudspeaker array at 30 m.

The directivity of the Intellivox loudspeaker arrays can be controlled by a number of parameters. Modeling the directivity data as a fixed directivity 'balloon' with an angular resolution of 1° or finer for each setting of these 'beam-steering' parameters, would require a lot of hard disk space. The distance dependency of the directivity (as will be described in the next section) would increase the amount of data even more. This procedure is also not very flexible with respect to the introduction of improvements in the signal processing algorithms. A more elegant way is to calculate the directivity during run-time of the acoustical prediction software for a specific setting of the controlling parameters [3], [4].

Fig 3 shows a comparison between simulated (line) and measured (dots) octave averaged vertical polar data at 30 m for an Intellivox-2c loudspeaker array (semi-anechoic measurement environment).

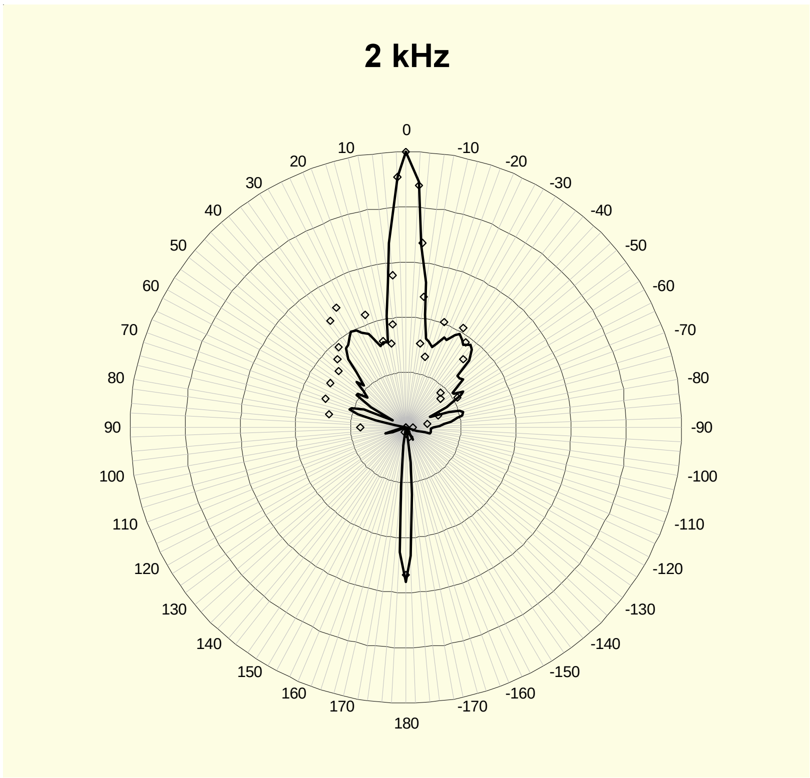

Fig 3 Measured and simulated vertical polar plot of an Intellivox-2c at 2 kHz, 6 dB/div.

3. Distance dependency.

For any real-life acoustical source it is important to discriminate between near field and far field conditions. In the far field of the source the wave propagation is purely spherical. As a result the sound pressure level is inversely proportional to the measuring distance (the 'inverse square law' holds). The directivity does not depend on the distance from the source to the measuring point. In the more complicated near field however, the directivity may heavily depend on the measuring distance.
In this section we will show that for long loudspeaker arrays, fairly large measuring distances are required to obtain true far field conditions. A large part of the audience area usually will be located in the near field, or in the near- to far field transition area, of the loudspeaker array.

Consider the representation of a line array as schematically shown in Fig 4. To be able to describe the directivity we need a reference point for the source. If the source was a simple enclosure with only one loudspeaker this reference point usually coincides with the acoustical center of the transducer (loudspeaker). In the complex case of a DSP controlled loudspeaker array however, no single acoustical center can be defined while measuring in the near field.

In the case of Fig 4, ***r*** represents the horizontal distance from the reference point to the measuring point ***P***. ***L*** is the vertical distance from the reference point to the top of the array. For an asymmetrically configured array this distance is almost equal to the physical length of the radiating (=active) part of the array. If the array configuration is symmetrical, the reference point will be in the center of the array. In the latter case ***L*** equals half of the length of the active part of the array.

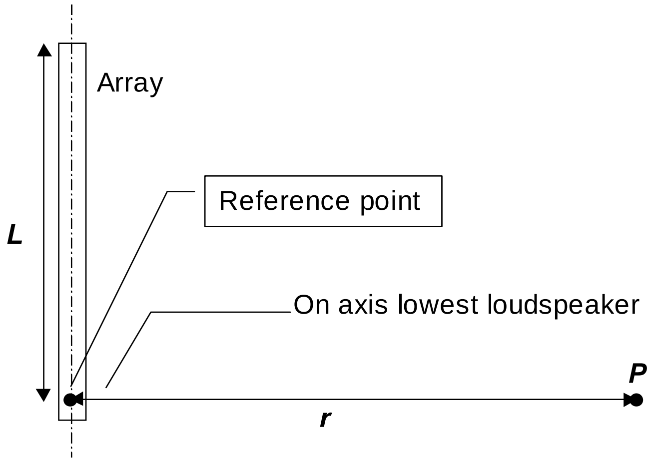

Fig 4 Side view of an asymmetrical loudspeaker array.

One way of determining the start of the far field area is to put a constraint on the coherency of the sound pressure contributions of the individual elements that make up the array. If we require that the maximum difference in path lengths from the individual transducers to point ***P*** is much smaller than half a wavelength the following equation will be the result [2].

In this equation λ represents the wave length. In a first order approximation of the square root it can be shown that the following two conditions must hold.

At a first glance we can say that especially the second condition will require large values for ***r*** in the case of long arrays if the frequency is high (small wave lengths).

Let's take the Intellivox-6c as an example. This asymmetrically configured array contains 32 loudspeakers (of 4" diameter), the physical length of the loudspeaker section is approx. 4.2 m. This means that the maximum value of ***L*** is about $12 \cdot \lambda$ for a frequency of 1 kHz. In order to meet the second condition the measuring distance should in this case be much larger than 49 m.

The signal processing scheme, which is implemented in the Intellivox DSP controlled loudspeaker arrays, reduces the effective length of the radiating part as the frequency increases. As a result excessive far field distances are avoided for higher frequencies.

Fig 5 shows the 'on axis' octave averaged Sound Pressure Level as a function of the measuring distance for the Intellivox-6c. The red line represents the theoretical response for a line array in the near field (the SPL drops 3 dB per distance doubling).

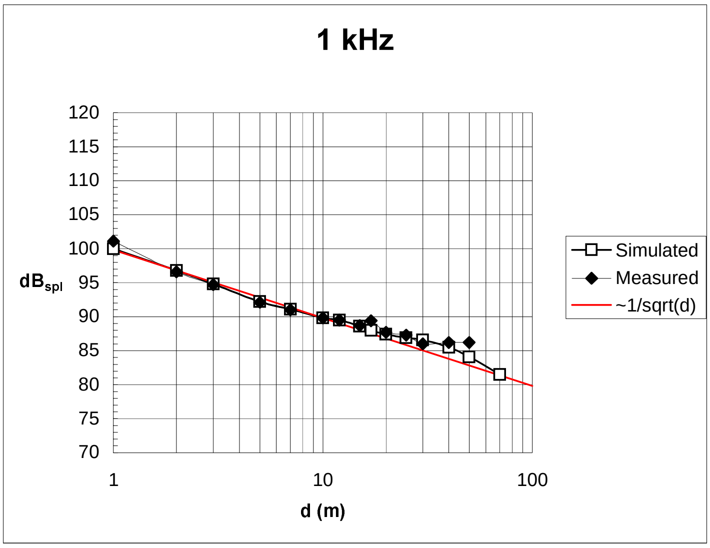

Fig 5 'On axis' SPL versus distance example for an Intellivox-6c loudspeaker array.

Refer to Fig 6 for an overview of simulated polar plots of an Intellivox-6c for various measuring distances (2 kHz, single frequency). Even between the results at 30 m and 70 m there is a noticeable difference.

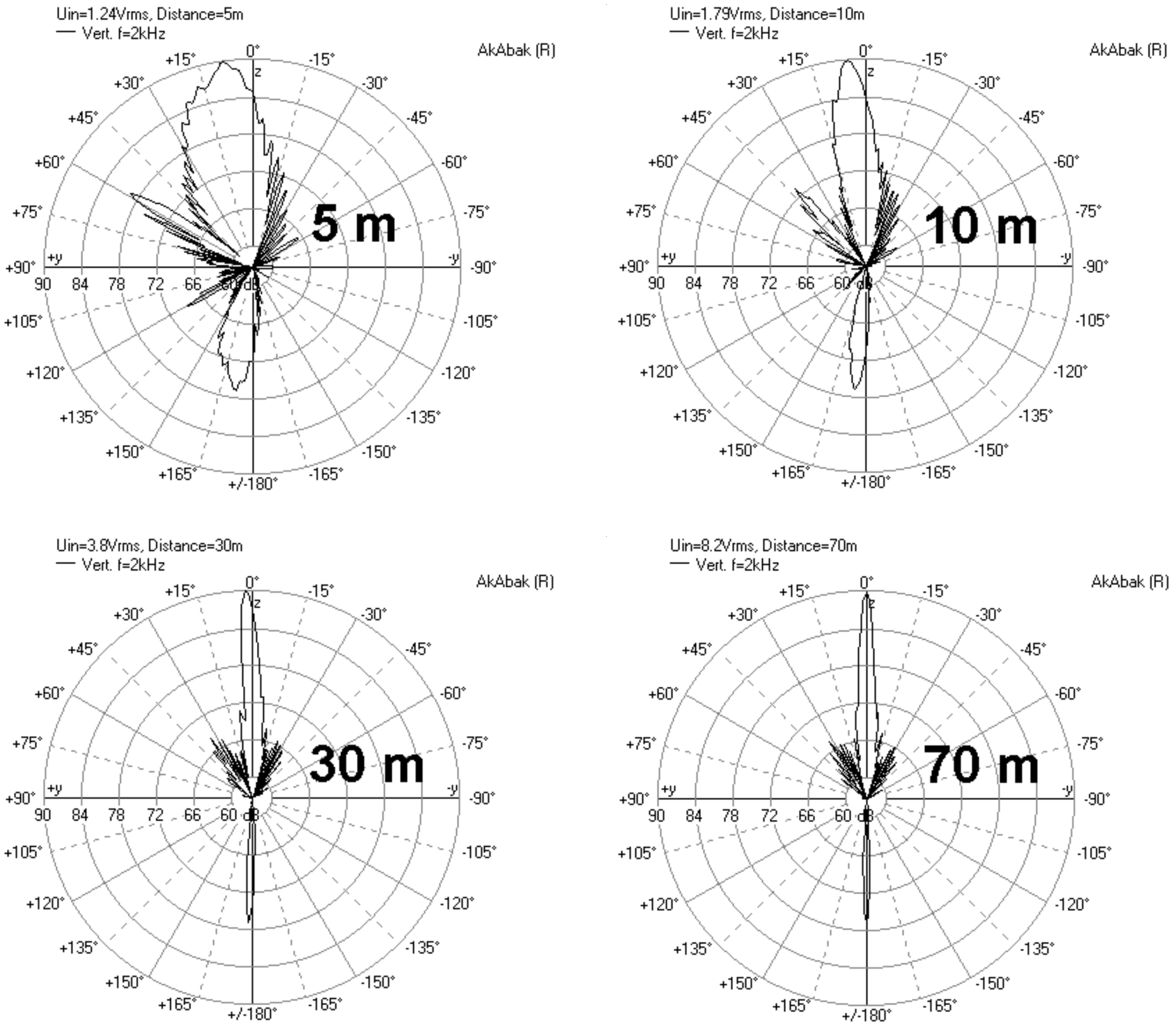

Fig 6 Simulated vertical polar plots of an Intellivox-6c at various distances.

4. Conclusion.

The de-facto standard of modeling the directivity as a fixed ‘balloon’ in 10° intervals is insufficient for large loudspeaker arrays at high frequencies. The angular resolution needs to be around 1° for accurate modeling of vertical polar patterns with very narrow main lobes (beamwidth of a few degrees in the far field). Because it is not uncommon that near field conditions exist up to 100 m from the array, the directivity model should incorporate distance dependency.

5. Literature.

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