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RANDOM PHASE ARRAYS

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Abstract

The usual aim of array design is to direct the beam of the array either towards or away from a given direction. However, there are applications where a wide polar pattern is desirable, such as surround channels in sound reproduction, or acoustical measurements. The paper describes achieving such a polar pattern using arrays where the individual transducers are fed with randomly phased signals.

Keywords: *loudspeakers, transducer arrays, array processing, directivity*

1. Introduction

The usual aim of array design is to direct the beam of the array either towards or away from a given direction. However, there are applications where a wide polar pattern is desirable, such as surround channels in sound reproduction or acoustical measurements. The paper describes achieving such a polar pattern using arrays where the individual transducers are fed with randomly phased signals.

The traditional array design relies on the individual transducers of the array having a precisely optimized phase and amplitude. The most typical way of implementing a wide polar pattern is apply shading (frequency-dependent attenuation) to transducers towards the edge of the array, possibly also changing the spacing between the array elements. Wide polar pattern is achievable also through delaying the transducers in the group. The extreme case for delay based processing is wave field synthesis, where the sound field of the selected virtual source is emulated. Bessel arrays are another approach to wide polar pattern. In them the weights of individual transducers are defined by Bessel functions, and in interesting special cases the weights are unity magnitude, with alternating sign. The paper discusses the properties of these approaches.

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The new method proposed in this paper is to apply unity magnitude, random phase filter individually to each transducer. This creates a polar pattern that varies with frequency, but the frequency average of the polar pattern approaches that of the individual transducers regardless of the number or spacing of the transducers. The properties of the array and the length of the filter affect, however, the smoothness of the average polar pattern within a given bandwidth. The random array can also be regarded as an ideal distributed mode (DML) loudspeaker. Numerical examples of array behaviour are discussed in the paper.

2. Conventional approaches to creating wide polar pattern arrays

2.1 Shaded and delayed arrays

The most widely applied technologies for constant beamwidth transducer arrays include frequency dependent shading, often combined with delays [1]. This approach allows flexible control of polar patterns, but especially if amplitude shading is used, the total power handling capacity of all the transducers is not fully utilized.
The acoustical shading using absorptive wedges to partially cover a loudspeaker array, proposed by Klepper and Steele in 1962 [2] presents another approach to polar pattern control. This method provides well-behaved polar patterns through gradual frequency-dependent absorption, but at the expense of unavoidable acoustical output reduction, and the design is constrained.
Wave field synthesis [4] allows creating practically any source distribution, including virtual point sources, but at the expense of complex signal processing.

2.2 Bessel arrays

Kitzen, based on earlier unpublished work by N. V. Franssen, presented [4] a conceptually different approach to omnidirectional radiation. He proved that if the amplitude weights of an infinite linear array are determined according to the values of Bessel functions $J_n(z)$ of the first kind for real values of z, the radiation pattern of the entire array is equal to that of an individual transducer.
The practical usefulness of Bessel arrays stems from an interesting property of the values of Bessel functions at low integer values of the argument: if we calculate the ratios of $J_n(z)$ for low values of n (-2 - 2) and for a selected value of z

(Kitzen used *z* = 1.5 for his example), then the ratios values of Bessel functions are

$$J_2{:}J_1{:}J_0{:}J_{-1}{:}J_{-2} = 0.23{:}\,0.56{:}\,0.51{:}\,0.23 \qquad (1)$$

These can be approximated by simple integer ratios:

$$a_2{:}\,a_1{:}\,a_0{:}\,a_{-1}{:}\,a_{-2} \approx 1{:}\,2{:}\,2{:}-2{:}\,1 \qquad (2)$$

These weights can be implemented simply by suitable wiring of the drivers (Figure 1).

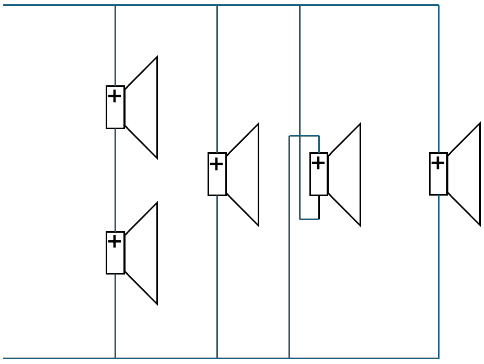

Figure 1. The schematic diagram of a 5-element Bessel array, showing the amplitude weightings achieved by series connection and out-of-phase wiring.

Don Keele has shown in his extensive analysis [5] that a 5-transducer array is the best choice for at least small truncated arrays (Keele didn't study arrays larger than 9 transducers). The polar patterns of the Bessel arrays are quite smooth, as shown in Figure 2.

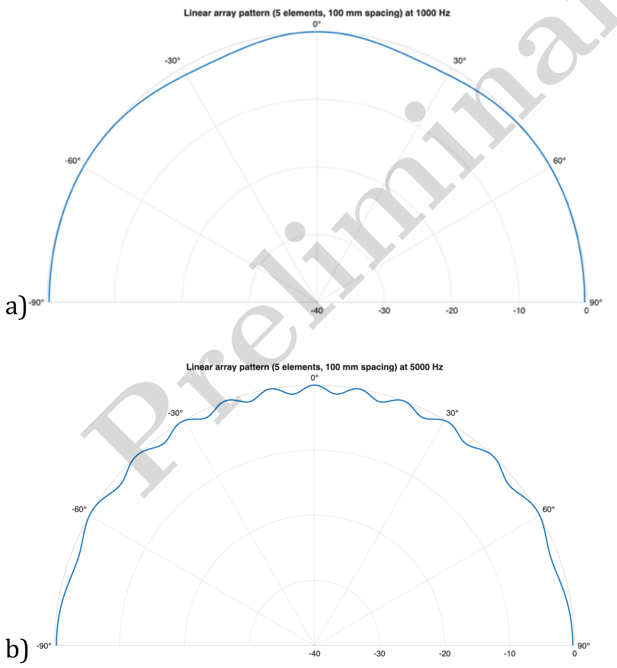

Figure 2. Polar patterns of linear 5-element Bessel arrays in an infinite plane at a) 1 and b) 5 kHz, source spacing 0.1m.

2.3 Allpass arrays

Allpass arrays, introduced by Michael Goodwin [6] are an interesting extension of the Bessel array concept. The Bessel arrays above relied on approximate weighting coefficients, allowing a very simple implementation using series/parallel connections and out-of-phase wiring. If individual amplifiers and signal processing are used for each transducer, the desired weights can be implemented more precisely. This creates even smoother polar patterns than the Bessel arrays discussed above.

3. Random phase arrays

3.1 The principles of random phase arrays

This paper presents a new approach to generating an essentially omnidirectional radiation using an arbitrary transducer configuration.

The structure of a random phase array is illustrated in Figure 3. The system consists of individual signal processing blocks and amplifiers for each transducer, with each FIR filter designed to have unit magnitude response, but with separate random phases for each transducer channel.

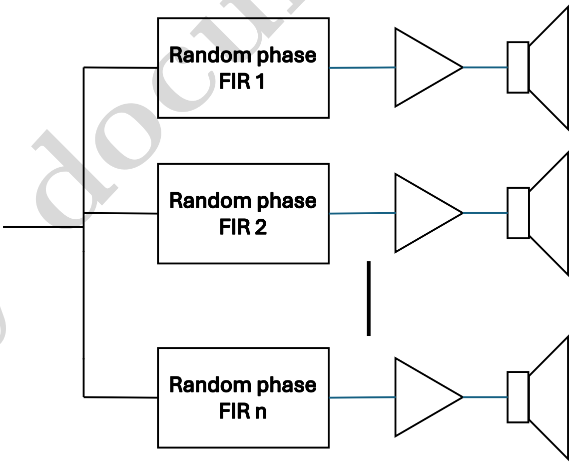

Figure 3. Implementation of an *n*-element random array.

The challenge of this approach is that the impulse response of a unit magnitude, random phase filter resembles random noise. If the filters are long, this may introduce audible artefacts on transients, and thus listening tests will be needed to determine the maximum filter length.

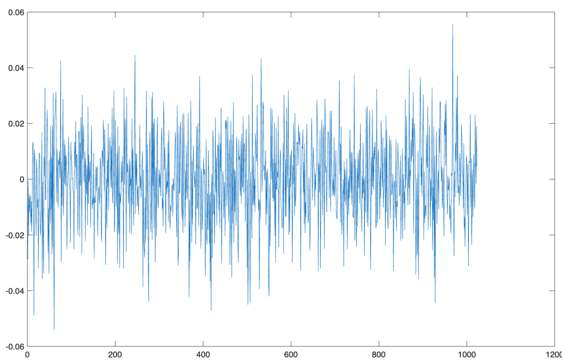

Figure 4. An example of impulse responses of a unit magnitude, random phase filter.

The random phase array can also be thought to be an extension of the Distributed Mode Loudspeaker [7], where a pseudo-random vibration of a continuous radiating surface is created by shaping the surface and choosing the actuator locations so that the modes of the surface are excited as evenly as possible. The limitation of the DML approach as compared to the proposed approach is that the parts of the surface remain correlated at each frequency, and a completely flat amplitude distribution across the entire surface cannot be achieved.

3.2 Polar pattern of random arrays

Figure 5 shows examples of polar patterns of a random phase array with dimensions similar to the earlier Bessel array example. The polar pattern is not as smooth as that of the Bessel array, but especially at high frequencies (wavelength < transducer spacing) the random array has equal-amplitude side lobes, and the directions of the side lobes are random.

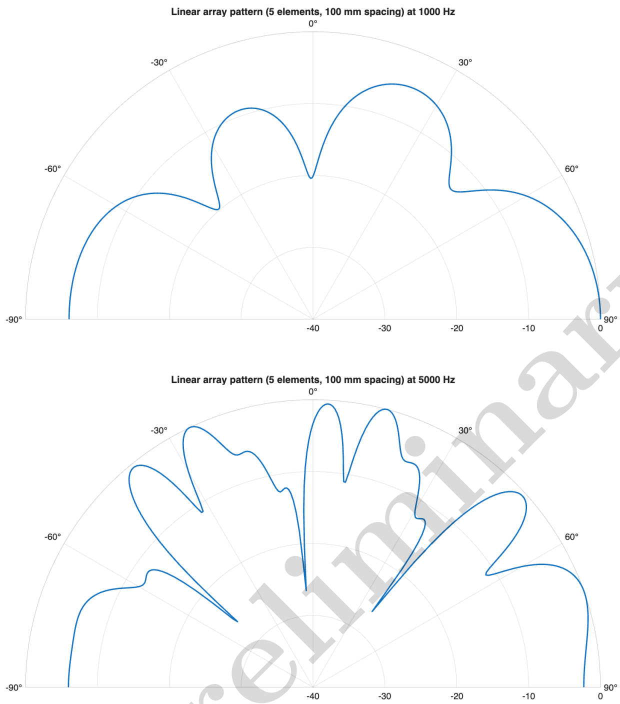

Figure 5. Polar patterns of a 5-element random array.

3.3 Radiated power and boundary effects

The overall sound power output from random arrays is highly irregular at low frequencies, but becomes quite smooth when the wavelength is smaller than the length of the array (Figure 6). It is interesting to see that the average power output at low frequencies is approximately equal to a Bessel array, but the random array has more high-frequency output.

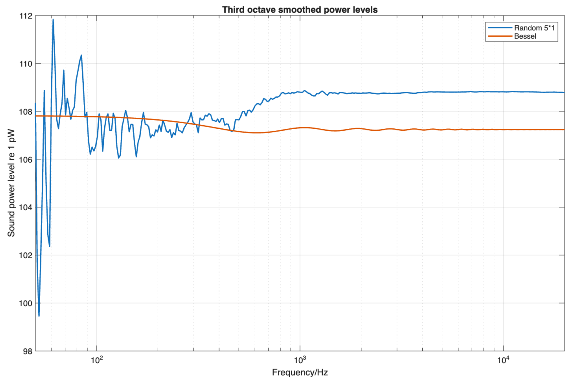

Figure 6. Third octave smoothed sound power levels of 5*1 element random and Bessel arrays.

One of the interesting properties of random arrays is their interaction with boundaries. Figure 7 shows the sound power gain from a hard infinite boundary at 0.5 distance from the centre of the array for various configurations: random arrays of 5*5 and 5*1 elements, 5-element Bessel array, an omnidirectional monopole source, and, as a reference, also a directive 5-element array with equal amplitudes. (The radiated power of a monopole source could also be calculated analytically [8]) The Bessel array and the monopole source both exhibit ripple in the total power, but random arrays, though having narrow-band irregularity, do not exhibit the ripple observed in other omnidirectional sources when the distance from the reflecting plane exceeds a quarter wavelength. The directive line source radiates at high frequencies only a small part of the power towards the plane, eliminating the effect of boundary reflection on the sound power.

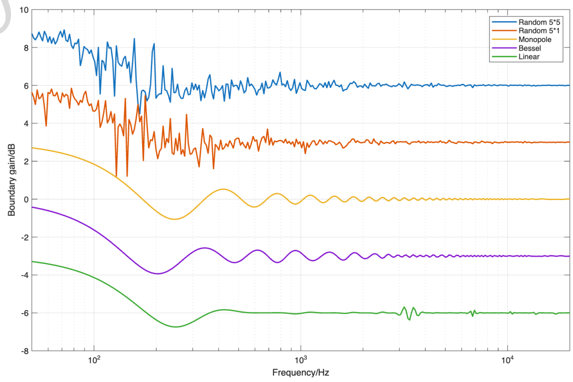

Figure 7. Boundary gains for different array configurations (offset by 3 dB).

4. Conclusions and future work

Random phase arrays are an interesting new approach for generating omnidirectional sound sources. Although traditional approaches, such as Bessel arrays, offer very smooth polar patterns, the random phase arrays interact with boundaries in a manner not found in other source configurations. Further work is needed, however, to determine optimal filter lengths to ensure freedom from audible artefacts and a minimum feasible number of transducers, and to study computationally more efficient alternatives.

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