Co-array Weighting in Minimum-Redundancy Arrays for Radar Image Enhancement

Kamil Rezer, Arne F. Jacob
Institut für Hochfrequenztechnik, Techn. Univ. Hamburg-Harburg
Denickestrasse 22, 21073 Hamburg, Germany
kamil.rezer@tuhh.de

***Abstract*— The pronounced lobing of minimum-redundancy arrays – a class of thinned arrays – leads to image degradation in radar applications. Co-array weighting is investigated as a possible cure. Different distributions are considered. A comparative study of pattern degradation caused by random phase errors of the individual array elements is conducted. Multiple target detection – a critical aspect of nonlinear array processing – is addressed as well in this context. The potential of the proposed approach is critically assessed by simulation. The findings are confirmed by Ka-band radar experiments performed with a synthetic array.**

I. Introduction

Digital beamforming (DBF) is a promising antenna technology in many applications as it combines flexibility, functionality, and speed. A drawback is the required hardware and ensuing overall system complexity. Array thinning is a possible and well understood solution to this problem. Particularly high thinning rates of up to 80 % and beyond are achievable with so called minimum-redundancy arrays (MRA). A detailed treatment of this approach can be found in [1] where linear arrays are considered.

These considerable thinning rates, however, come along with the appearance of side lobes when conventional beamforming is performed. Array element weighting turns out to be unreliable [2]. To overcome this limitation, Hoctor suggested to perform beamforming with the spatial autocorrelation sequence, also called co-array and calculated from the array output [2]. Conventional beamforming can then be applied to the co-array if its geometry exhibits spatial periodicity. Because most of co-arrays associated with MRA fulfill this condition co-array weighting is applied here in order to achieve low sidelobe level in the corresponding power pattern.

From its principle, co-array operation is fundamentally nonlinear. Although non-linear array processing is widely used in high-resolution imaging, it can also lead to a considerable reduction in image quality. This happens, in particular, when the array elements exhibit random position errors as caused by fabrication tolerances or if the incident signals are correlated. Indeed, position tolerances result in phase errors which, in turn, deteriorate the array pattern, particularly by increasing the sidelobe level. Cross-correlative beamforming using subarrays may especially suffer from high sidelobe peaks due to this effect [3]. Although such peaks are associated with a degradation in the dynamic range they only occur sporadically and are thus best described by their probability of occurrence. The latter can be estimated by employing the concept of the peak sidelobe level (PSL) introduced in [4]. The PSL is defined as the level that will not be exceeded with some given probability called confidence level.

A further disadvantage associated with non-linear beamforming are spurious crossproducts occurring in the co-array spectrum if one deals with multiple, correlated target responses. Such crossproducts can distort the spectral appearance of real targets or could be perceived as parts of the real scene [5]. In the case of cross-correlative beamforming with two periodic subarrays exhibiting different element spacings, crossproduct content in the image can be reduced by applying difference pattern processing [5]. If, on the other hand, the elements of a thinned array are arranged periodically, the image resolution can be improved by applying the generalized spatial smoothing concept [6]. Both these methods, however, are unsuitable for MRA which, in general, feature periodicity neither in some subarrays nor in the element arrangement.

Some improvement of the multiplicative spectrum can also be achieved by restricting the negative sidelobes occurring during normalization of the co-array response, a processing step which is applied in radio astronomy for incoherent imaging [2]. Here, the negative sidelobe constraint is considered in conjunction with co-array beamforming for radar imaging with MRA. Afterward, the method is demonstrated experimentally with help of a synthetic array at Ka-band.

II. Co-array Weighting

The non-linear beamforming by co-array weighting proposed here for image enhancement with MRA is schematically shown in Fig. 1. Since the co-array is determined by the autocorrelation function, it can be calculated either by the spatial convolution of the MRA output with its reverse and conjugate complex duplicate or by the inverse Fourier transformation of the initial power spectrum corresponding to the array response [2].

For a detailed investigation of co-array beamforming, a ten element linear MRA is chosen. The element positions are taken from [1] and are given as (0 0.5 1.5 3 6.5 10 13.5 15.5 17.5 18)$\cdot\lambda$, where λ is the free space wavelength. The thinning rate of the array is about 73 % compared to a periodic array of the same aperture length and with halfwave element spacing.

Although the initial co-array of the MRA is spatially periodic, its power pattern exhibits high sidelobes, as shown by the