Design of linear arrays by employing randomly-overlapped subarrays

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Abstract

Some applications require a highly-directive antenna array which has to scan the main beam over a limited-field-of-view (LFOV) angular sector. The phase control over the radiating aperture can be achieved with phase-shifters or time delay units (TDUs). Due to their cost and bulkiness time delay units can be hardly employed at element level and their number needs to be minimized as much as possible. On the other hand, the use of phase shifters may cause a beam squint or a narrow band operation if compared to employing TDUs. A quite common solution adopted to overcome the aforementioned issues for such radiating structures relies on the employment of time-delayed subarrays for reducing the costs and allowing an easier practical realization. The present work investigates on the possible performance improvements provided by arrays organized into randomly-overlapped subarrays with respect to other subarray arrangements such as contiguous and uniformly-overlapped lattices.

1. Introduction

The increasing need of arrays able to provide both wide bandwidth and high directivity beam has recently fostered a renewed interest in improving the state-of-the-art subarray technology. New solutions are particularly appealing in the framework of Limited Field of View (LFOV) arrays for space applications. In this scenario, synchronous satellites systems usually scan a high-directivity beam over angles of few degrees to map the ground surface or to cover small areas. In order to satisfy these requirements arrays of large size are necessary. The radiating elements of such large arrays are efficiently grouped into subarrays for reasons of scalability, mechanical constraints and limitation of the number of Time Delay (TD) controls required for wideband beam scanning [1]. However, time delay control of each element in scanning arrays is considered an unfeasible option because of the difficulty of implementing TDs at the element level or switched TD lines [2]. Digital or optical beam forming networks can successfully introduce a time delay at element or subarray level even though this solution has a significant impact on the system cost. Therefore it is often convenient to introduce time delay at the subarray level in order to employ a relatively small number of time delay units.

For the aforementioned reasons, the configurations addressed in this work for LFOV arrays do not exploit TD units at element level but the delay lines are supposed to be connected at the input port of each subarray in order to perform the beam scanning.

The simplest way of organizing the array into subarrays is to group the radiating elements into identical contiguous subarrays that are uniformly distributed across the radiating aperture [3]. Unfortunately this periodic arrangement is affected by quantization lobes that occur at the grating lobe locations of the array created by the subarray phase centers. As a matter of fact, the quantization lobes arise because the subarray pattern radiates broadside and is stationary, whereas the array factor is scanned. Although it is possible to adopt a suitable subarray spacing to suppress the quantization lobes during the main beam scanning, this criterion represents a theoretical upper bound limit because is achieved only by using an idealized pulse-shaped subarray pattern [4]. Among the techniques that try to reach this upper bound limit, one of the best solution is represented by the so-called dual transform or overlapped subarray network. This configuration employs a multiple-beam feed and a focusing lens to form a periodically-spaced and completely-overlapped set of beams illuminating an aperture for radiating an approximately pulse-shaped subarray pattern [5]. Although this solution provides high performances, such a system is not compact since the overall feed network may be quite bulky and because an amplitude tapering is required at subarray level at least to achieve low sidelobe levels.

Another strategy to overcome the quantization lobe problem relies on exploiting aperiodicity and randomness in the radiating element arrangement or excitations [6]-[8]. These methods may produce a sparse array covering electrically-large areas thus avoiding the insurgence of the quantization lobes determined by the periodic element lattice. Another way of reducing the quantization lobes relies on altering the array periodicity by randomly placing

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subarrays with suitable dimensions in order to decrease the number of required TD units with a proper factor of aperiodic overlap [9]. This approach creates randomly-overlapped subarray layouts which allow reducing the sidelobe level without resorting to any amplitude tapering (neither at element nor at subarray level). Therefore a reduced side lobe level can be achieved without inserting the additional components required for tapering the amplitude of the input signals. This work will investigate the benefits of exploiting randomly-overlapped subarray configurations in comparison with non-overlapped and periodically-overlapped configurations.

2. Overlapped subarrays

Overlapped subarrays share one or more of the edge elements of the adjacent subarrays, so that each array element is connected to more than one time delay. To prove the effectiveness of subarrays that are randomly overlapped instead of being contiguously placed or periodically overlapped across the array, a linear array is considered as a test case. The linear array comprises 50 isotropic elements, which are half-wavelength-spaced apart at the upper frequency and arranged into 5-element subarrays. The performance of three array layouts (Fig. 1) are evaluated and compared. More in detail, the first one has 10 contiguous subarrays with (Fig. 1a), the second one comprises 16 uniformly-overlapped subarrays (Fig. 1b) whereas the last one has 16 randomly-overlapped subarrays (Fig. 1c).

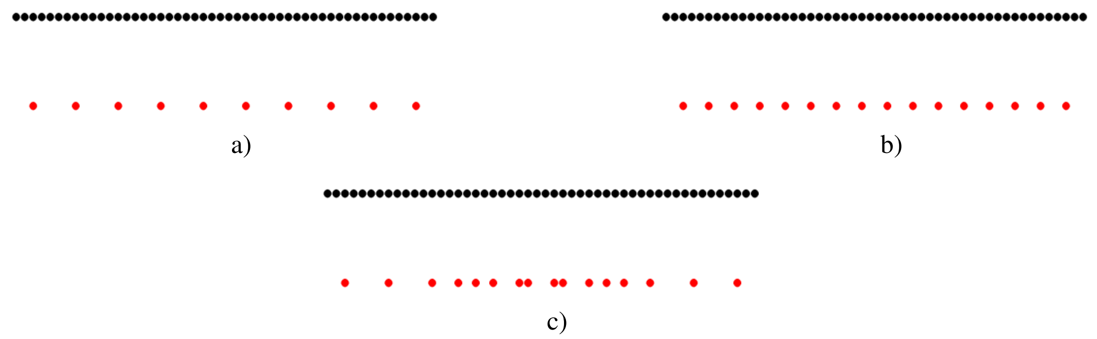

Figure 1. Array layouts. Antenna elements are indicated by the black dots while the phase centers of each subarray are in red: a) contiguous subarray; b) uniformly-overlapped subarrays; c) randomly-overlapped subarrays.

For each array layout the overall radiation pattern, the subarray pattern and the array factor are superimposed in Fig. 2, when the main beam is broadside at the upper frequency. Since the subarrays are identical and of the same size across all the three cases analyzed, the subarray pattern represented by the blue dashed line is simply the radiation pattern of 5 uniformly-spaced isotropic sources. Contrarily, the array factors (dashed red line) depend on the locations of the subarray phase centers and differ from case to case. More in detail, in Fig. 2a and Fig. 2b, as the subarray lattice is periodic, the array factor possess grating lobes that can be a potential issue in increasing the resulting peak sidelobe level. Furthermore, although the grating lobes can occur at the deep null location of the subarray pattern (Fig. 2a), the overall peak side lobe level is substantially given by the sidelobe of the array factor (around -13 dB). On the other hand, if the subarrays are randomly-overlapped, the array factor does not exhibit any grating lobes thanks to the irregular lattice of the subarray phase centers. In addition, the array factor sidelobes (Fig. 2a) in proximity of the main beam are lower than that of Fig. 2a and 2b due to randomness introduced in the array layout, thus determining a decrease of the peak side lobe level up to 20 dB below the main beam. Finally, as the array is scanned, it has to be notice that the randomly overlapped subarray array still outperforms both the contiguous and the uniformly-overlapped subarray array in terms of sidelobe level reduction. In addition the peak-to-side lobe ratio can be further improved if larger arrays are taken into consideration.

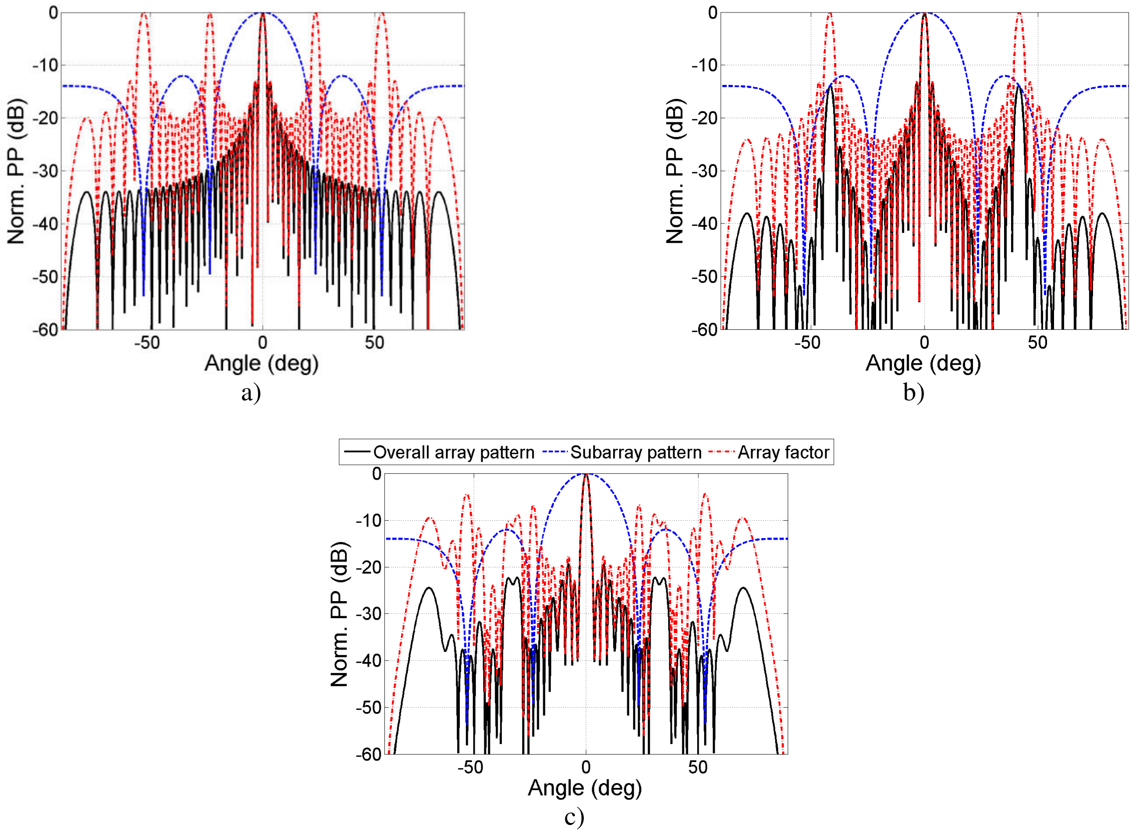

Figure 2. Radiation patterns for the analyzed configurations of Fig. 1: a) contiguous subarray; b) uniformly-overlapped subarrays; c) randomly-overlapped subarrays. The blue dashed line is the subarray pattern, the red dashed one the array factor and the continuous black one is the resulting array pattern.

3. References

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