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Introduction

Polarization-reconfigurable arrays play a fundamental role in radar systems in order to enhance their detection probability and cancel clutters, chaffs, and jammers [1]. In order to reach polarization flexibility, the integration of actively controlled elements in standard array configurations is often employed [2], but the overall system complexity and costs significantly increase [3]. To overcome such limitations, the use of two shared aperture arrays with independent polarizations was proposed in [3] by exploiting an interleaving scheme based on Difference-Sets (DSs). By combining the field generated by each sub-array, arbitrary polarizations, low sidelobes, large steering angles, and narrow beamwidths can be reached with a limited complexity of the underlying feeding network. Despite its theoretical and practical advantages, only few planar array geometries can be synthesized because of the limited number of available DS sequences [4].

A different set of binary sequences [called *Almost Difference Sets* (ADSs)] [5][6] with properties very similar to those of DSs has been recently investigated. Besides their application in code theory [5], ADSs have already shown their effectiveness in synthesizing thinned arrays with low and predictable sidelobes [7][8].

This paper analyzes the properties of polarization-flexible planar arrays based on ADSs. Numerical simulations are presented and discussed by focusing on the sidelobe level control and the polarization selectivity of the synthesized ADS arrays.

ADS-Based Interleaved Array Design

Let us consider a planar array with $N = P \times Q$ elements spaced by $s_x \times s_y$ wavelengths. Let the elements be grouped into two sub-arrays with K_I and $K_C = N - K_I$ elements and let us suppose that each sub-array is composed by identical elementary radiators. The field radiated by the array is

$$\begin{aligned}\mathbf{E}(u,v) = {} & \mathbf{E}_I(u,v) A_I \sum_{p=0}^{P-1}\sum_{q=0}^{Q-1} w_I(p,q)\exp\left[i2\pi(ps_x u + qs_y v)\right] \\ & + \mathbf{E}_C(u,v) A_C \sum_{p=0}^{P-1}\sum_{q=0}^{Q-1} w_C(p,q)\exp\left[i2\pi(ps_x u + qs_y v)\right]\end{aligned} \qquad (1)$$

where A_I and A_C are the complex polarization coefficients [3], $\mathbf{E}_I(u,v)$ and $\mathbf{E}_C(u,v)$ are the fields radiated by the elementary radiators in the two sub-arrays, $w_I(p,q) \in \{0,1\}$, $w_C(p,q) \in \{0,1\}$, $w_C(p,q) = 1 - w_I(p,q)$ ($p = 0,..,P-1$, $q = 0,..,Q-1$), and $\sum_{p=0}^{P-1}\sum_{q=0}^{Q-1} w_I(p,q) = K_I$.

By exploiting the following theorem

> *Theorem I [9]*: if D_I is a (N, K_I, Λ_I, t_I)-ADS, then its complementary set $D_C = Z^N \setminus D_I$ is a (N, K_C, Λ_C, t_C)-ADS with $K_C = N - K_I$, $\Lambda_C = N - 2K_I + \Lambda_I$

an ADS-interleaved layout is defined setting the array coefficients as follows [8]

$$w_I(p,q) = 1 - w_C(p,q) = \begin{cases} 1 & if\ (p,q) \in D_I \\ 0 & otherwise \end{cases} \tag{2}$$

where D_I is a (N, K_I, Λ_I, t_I)-ADS. More specifically, an ADS is a subset $D_I = \{a_I \in Z^N; i = 0,...,K_I - 1\}$ of an Abelian group Z^N of order N for which the multiset $R = \{r_j = a_h - a_l, a_h \neq a_l, j = 0,...,K_I(K_I - 1) - 1\}$ contains t_I nonzero elements of Z^N exactly Λ_I times, and the remaining $N - 1 - t_I$ exactly $\Lambda_I + 1$ times [7][8], whose periodic autocorrelation function exhibits a three-level behaviour [7][8].

Starting from a single reference ADS, other $P \times Q$ layouts still ADSs are then generated thanks to the ADS cyclic shift property [8] and a large set of trade-off solutions are now available.

Numerical Results

In order to assess the efficiency of ADS-based interleaved polarization-flexible planar arrays, a set of numerical simulations has been carried out. For illustrative purposes, flanged apertures of size $0.5\lambda \times 0.25\lambda$, excited with a TE_{10} mode, and spaced by $s_x = s_y = 0.65\lambda$ have been considered as elementary radiators.

The radiated field has been evaluated with the infinite-ground plane model [10]. As a representative test case, the steering angles have been set to $u_0 = v_0 = 0.353$ and the following objective

$$\varepsilon_d(u,v) = \begin{cases} -\pi/4 & u,v \in M \\ \pi/4 & otherwise \end{cases} \quad . \tag{6}$$

has been assumed for the polarization ellipticity.

Besides the peak sidelobe level

$$PSL = \frac{\max_{u,v \notin M} |\mathbf{E}(u,v)|^2}{|\mathbf{E}(u_0,v_0)|^2} \tag{5}$$

(M being the mainlobe region, and u_0, v_0 the mainlobe direction), the value of the polarization purity index

$$\Sigma = \frac{\int [\varepsilon(u,v) - \varepsilon_d(u,v)]^2 \, du \, dv}{\int [\varepsilon_d(u,v)]^2 \, du \, dv} \quad (5)$$

has been evaluated. In (5), $\varepsilon_d(u,v)$ and $\varepsilon(u,v)$ are the desired and obtained polarization ellipticity angles [10], respectively.
Figure 1 summarizes the performances of the ADS layouts generated from the (121,61,30,60)-ADS (*P=Q=11*) [6] in terms of PSL values and polarization indexes.

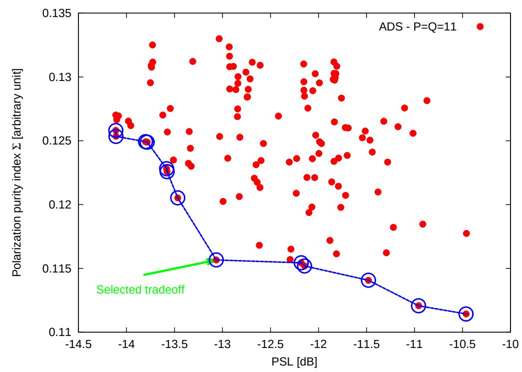


Figure 1. Behaviour of Σ as a function of the PSL for the interleaved arrangements derived from the (121,61,30,60)-ADS.

As it can be noticed, several trade-off solutions are obtained with controlled sidelobes and good polarization matching. Moreover, more than 10 "Pareto solutions" have been synthesized by a single ADS by confirming the flexibility of the ADS-based designs when dealing with non-regular interleaved arrays.

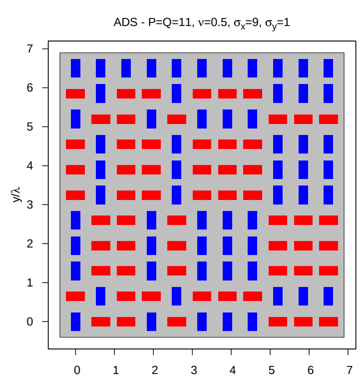
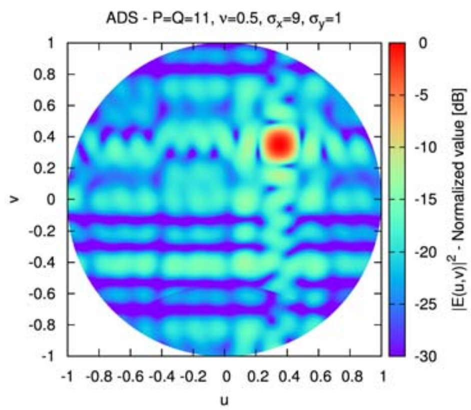


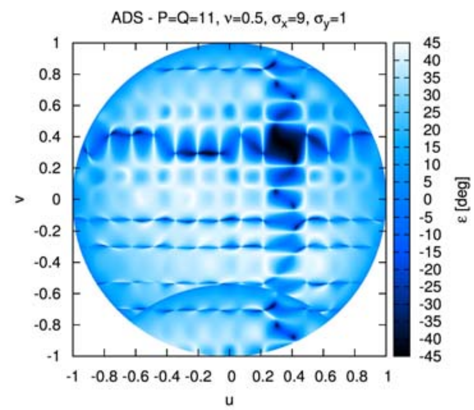
Figure 2. Geometry of the tradeoff ADS array. Colors identify sub-arrays.

For completeness, the plots of $|\mathbf{E}(u,v)|^2$ and $\varepsilon(u,v)$ in correspondence with a trade-off layout (Fig. 2) are reported in Fig 3. As it can be observed, the arising

$\varepsilon(u,v)$ values turn out to be close to the desired one within the whole visible range despite the simple feeding scheme (only two coefficients, namely A_I and A_C, control the array polarization) [Fig. 3(*b*)].



(*a*) Total radiated power.



(*b*) Polarization ellipticity.

Figure 3. Radiation features of the selected ADS tradeoff.

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