E-DPCA Synthesis Technique in Small Linear Array Antennas with Tapered Edge Elements

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***Abstract*— The side and minor lobe levels of a small, equally-spaced linear array antenna are effectively reduced without any physical displacement, by utilizing the electronically displaced phase center antenna technique (E-DPCA) in conjunction with the tapered edge elements. As opposed to conventional single-mode elements, whose phase center locations are fixed, over-moded antenna elements with the E-DPCA capability are employed to realize an electronically aperiodic array out of a seven-element, linear, periodic array. It is shown that the resultant side and minor lobe levels are reduced to about -25 dB using the proposed E-DPCA technique and tapered edge elements.**

Keywords*— *Phased arrays, edge tapering, element spacing, sidelobe level (SLL), electronically displaced phase center antenna (E-DPCA).

I. Introduction

Phased array antennas have gained popularity in fields such as radar, communications, remote sensing and navigation systems, due to their intriguing capabilities of realizing a variety of unique radiation characteristics [1]. Complex excitation techniques are often utilized in equally-spaced array antennas to generate desired radiation patterns with low side and minor lobe levels [2-3]. Aperiodic arrays, on the other hand, achieve the characteristic radiation patterns with low sidelobe levels (SLL) by physically varying the spacing between their adjacent elements. A variety of evolutionary algorithms have been developed to determine optimal inter-element spacing in aperiodic arrays and the amplitude tapering in equally-spaced arrays to generate patterns with reduced side and minor lobe levels [4-6]. However, in aperiodic arrays, the element position once fixed satisfies only one criterion at a time and the elements need to be rearranged in order to meet any other requirement. This increases the cost and complexity of the design and makes it quite rigid. Therefore, a novel technique of electronically changing the relative coordinate of each element by displacing the phase center locations of dual-mode antenna elements in linear array antennas (E-DPCA) was proposed by the authors in [8-10] to modify the radiation pattern without any physical displacement. When combined with the array thinning in large linear array antennas, it was shown that one could achieve SLLs as low as -21 dB. However, in small linear array antennas, about 4-5dB SLL reduction is achievable using the E-DPCA technique only and array thinning is not quite feasible. To further suppress the side and minor lobe levels, the amplitude distribution of the edge elements only is tapered to form a symmetric stepped function and the corresponding results are shown in this paper for a seven-element, equally-spaced, linear array antenna.

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II. Seven-Element E-DPCA Linear Array

Dual-mode circular patch antennas described in [8] have the ability to displace their phase center location by exciting the higher order TM_{21} mode along with the dominant TM_{11} mode. The magnitude and direction of the displaced phase center location is determined by the elements' mode content factor, defined as $A_{21} = |A_{21}|\angle\alpha_{21}$, where $|A_{21}|$ and α_{21} represent the magnitude and the phase shift between the two modes, respectively. This dual-mode circular patch antenna is employed as the base element of a seven-element linear array symmetrically arranged about the *x*-axis, as depicted in Fig. 1. The base elements of the array are uniformly spaced $0.7\lambda_0$ apart, where λ_0 is the free space wavelength at 10 GHz. The phase centers of each element are initially located at their physical centers when only the TM_{11} mode is excited. This is represented by the black "eye" symbols in Fig. 1. This array configuration generates a radiation pattern with a -13 dB SLL and 16.6 dBi peak gain. To suppress the side and minor lobe levels without any physical means, the equally-spaced array is electronically reconfigured into an aperiodic antenna by symmetrically exciting the TM_{11} and TM_{21} modes and displacing the phase centers of the elements away from their physical centers. The in- and out-of-phase excitations within the base elements are graphically illustrated by the blue and green "eye" symbols, respectively, within the elements in Fig. 1. The E-DPCA array generates a radiation pattern with the SLL of -17.7 dB and peak gain of 16.2 dBi.

To further suppress the side and minor lobe levels of the seven-element E-DPCA array, the edge elements are symmetrically weighted with an amplitude taper of 0.3735. This edge taper further reduces the side and minor lobe levels to -25 dB, while the peak gain drops to 15.9 dBi. In contrast, the equally-spaced, seven-element, linear array with the same edge tapering generates a radiation pattern with the SLL of -15 dB and gain of 16.4 dBi. The radiation pattern of the seven-element E-DPCA +edge tapered array is compared to that of the equally-spaced seven-element array with the same edge tapering in Fig. 2. It can be observed that the E-DPCA + edge tapering technique achieves better side and minor lobe reduction with a comparatively minor loss in overall gain of the array, which is only 0.3 dB. For further clarification, the amplitude coefficients of the proposed E-DPCA + edge tapered array are compared to those of the uniform and -25 dB Chebyshev array in Fig. 3. As observed, only 29%, *i.e.*, 2 out of 7 elements, are tapered to attain the -25 dB side and minor lobe reduction. Due to the array symmetry, the optimal mode content factors of the elements on the +*x*-axis of the E-DPCA + edge tapered array are summarized in Table I. The effective distances between the adjacent elements of the equally-spaced + edge tapered and E-DPCA + edge tapered array are graphically illustrated in Fig. 1 and detailed in Table II.

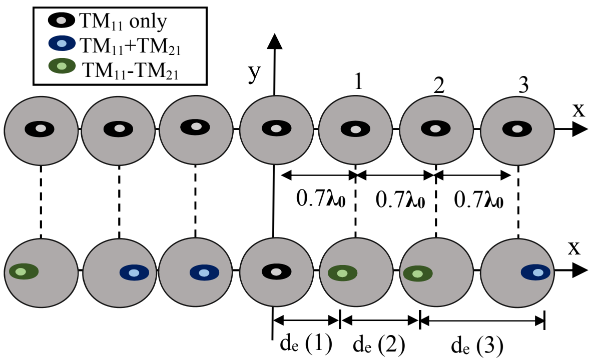

Fig. 1. Structures of the 7-element equally-spaced (top) and the proposed E-DPCA array (bottom), whose elements are physically placed $0.7\lambda_0$ apart and the edge elements are tapered to 0.3735. The adjacent phase center distances i.e. $d_e(1)$-$d_e(3)$ are summarized in Table II.

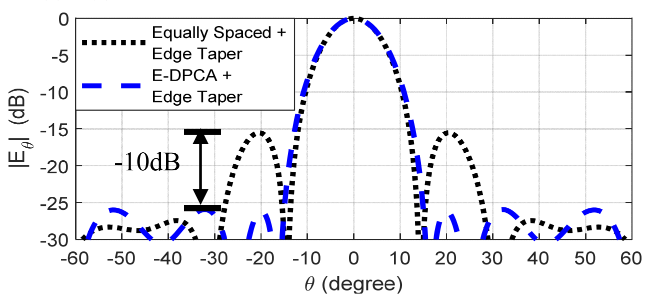

Fig. 2. Radiation patterns of edge-tapered, equally-spaced (TM_{11} only) and E-DPCA seven-element linear arrays presented in Fig. 1, with SLLs of -15 dB and -25 dB, respectively.

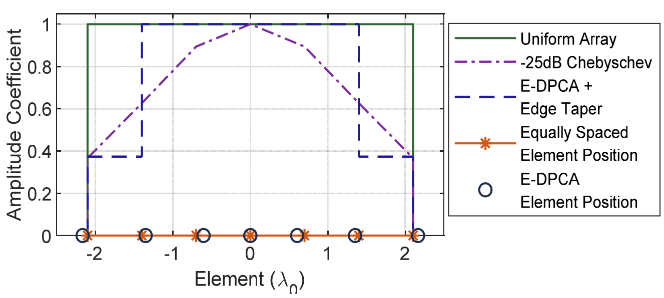

Fig. 3. Comparison of the proposed E-DPCA + edge tapered amplitude coefficients with uniform and -25 dB chebyschev distribution for a seven-element linear array with the equally-spcaed and E-DPCA element distributions.

Thus, the previously-established E-DPCA technique, combined with the tapered edge elements, facilitated side and minor lobe reduction to ~25 dB in a small seven-element linear array antenna without any physical displacement. As only the edge elements (2 out of 7 elements) are engaged in the amplitude tapering, the cost and complexity of the overall design is significantly less than that of the -25 dB Chebyshev antenna that engages 100% of the elements.

TABLE I
OPTIMAL MODE CONTENT FACTORS OF ELEMENTS ON THE +*X* AXIS IN THE SEVEN-ELEMENT LINEAR ARRAY ANTENNA

Element	E-DPCA + Edge Taper; SLL=-25 dB	
	$\lvert A_{21}\rvert$	α_{21}
1	0.9375	180°
2	0.2253	180°
3	0.7549	0°

TABLE II
EFFECTIVE DISTANCES BETWEEN ADJACENT ELEMENTS FOR SEVEN-ELEMENT LINEAR EQUALLY-SPACED AND E-DPCA ARRAYS

	Equally-Spaced (TM_{11}) + Edge Taper SLL = -15 dB	**E-DPCA + Edge Taper SLL = -25 dB**
d_e (1) λ_0	0.7	0.57
d_e (2) λ_0	0.7	0.79
d_e (3) λ_0	0.7	0.82

III. CONCULSION

In this paper, side and minor lobe reductions in small E-DPCA arrays were investigated by combining the E-DPCA synthesis technique with the tapered edge elements in a seven-element, equally-spaced, linear array antenna. It was observed that the combination of E-DPCA + edge tapering suppressed the SLL to -25 dB, which was 7.3 dB lower than just the E-DPCA technique and 10 dB lower than just the edge tapering. Thus, when the edge tapering is applied to small E-DPCA arrays it noticeably improves the arrays' SLL reduction capability. Additional case studies will be presented at the conference.

REFERENCES

[1] C. A. Balanis, *Antenna theory: Analysis and design*, 4th Ed. Hoboken, NJ:John Wiley, 2016.

[2] G. Thadeu Freitas de Abreu and R. Kohno, "A modified Dolph-Chebyshev approach for the synthesis of low sidelobe beampatterns with adjustable beamwidth," *IEEE Trans. Antennas Propag*., vol. 51, no. 10, pp. 3014-3017, Oct. 2003.

[3] A. Villeneuve, "Taylor patterns for discrete arrays," *IEEE Trans. Antennas Propag*., vol. 32, no. 10, pp. 1089-1093, Oct. 1984.

[4] A. Ishimaru, "Theory of unequally-spaced arrays," *IRE Trans Antennas Propag*, vol. 10, no. 6, pp. 691-702, Nov. 1962.

[5] R. Harrington, "Sidelobe reduction by nonuniform element spacing," *IRE Trans. Antennas Propag*., vol. 9, no. 2, pp. 187-192, March 1961.

[6] R. L. Haupt, "Thinned arrays using genetic algorithms," *IEEE Trans. Antennas Propag*., vol. 42, no. 7, pp. 993-999, July 1994.

[7] Keen-Keong Yan and Yilong Lu, "Sidelobe reduction in array-pattern synthesis using genetic algorithm," *IEEE Trans. Antennas Propag*., vol. 45, no. 7, pp. 1117-1122, July 1997

[8] Z. A. Pour, "Control of Phase center and Polarization in Circular Microstrip Antennas", Master of Science thesis, University of Manitoba, Winnipeg, Canada, July 2006.

[9] T. Mitha, M. Pour, "Principles of Reconfigurable Element Spacing Linear Array Antennas," *Nature, Scienticic Report,* 11, 5584, 2021.

[10] T. Mitha, M. Pour, "Sidelobe Reductions in Linear Array Antennas Using Electronically Displaced Phase Center Antenna Technique," *IEEE Trans Antennas Propag.,* early access, DOI: 10.1109/TAP.2021.3138499, 2022.