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Design of CCAA for Optimized Difference Patterns

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***Abstract*: Difference patterns find applications in target tracking radars for accurate target detection. Such patterns must be generated with minimum sidelobe levels to reduce the effect of interfering signals like clutter, jamming signals. The present work is focused on designing concentric circular arrays(CCA) of practical elements producing low sidelobe difference patterns using thinning. Simulated results are presented for 6 ring and 7 ring concentric circular antenna arrays.**

***Keywords* : Concentric circular antenna arrays (CCAA), Differential Evolution Algorithm, Difference patterns, Peak Sidelobe level.**

I. INTRODUCTION

Difference patterns are employed in radars for accurate target detection. Usually linear arrays are the first choice for antenna designers owing to their design simplicity. Concentric circular antenna arrays are steadily gaining more importance in antenna design because of their compact antenna structure and a beam which remains constant in the azimuthal plane. They are preferred than linear arrays as they offer more degrees of freedom to the antenna designer. These are used in various applications like radio direction finding, air and space navigation, mobile, sonar, radar and wireless communication applications [1]. Antenna arrays can be designed to obtain different types of patterns like sum patterns, difference patterns, sector beams, ramp patterns [2]-[5], stair case patterns and so on. Low sidelobe patterns are necessary to reduce problems that arise due to Electromagnetic Interference. Such patterns can be generated by different techniques like choosing proper array excitations, by varying spacing between elements [6]. Another way is to thin array elements. Thinning [7]-[8] allows sidelobe reduction at reduced number of active elements thus lowering antenna cost, weight and design complexity.

Several works were contributed in the field of difference pattern generation from circular arrays. Bayliss [9] developed a two parameter difference pattern with nearly equal side lobes similar to those of Taylors sum pattern for a circular aperture antenna. The resultant pattern has angle sensitivity that is in proportion with the given side lobe level. Elliot [10] proposed a perturbation technique which modifies the Taylor-type linear and circular aperture distributions to generate sum and difference patterns. The resultant patterns have arbitrary side lobe topography. Hansen [11] presented a synthesis method for linear and circular planar arrays that provide pencil beams and difference patterns with variable side lobe level based on placing zeroes. In [12] Ares Rengarajan, A. Vieiro and E. Moreno have shown a method to design an aperture distribution that results in difference patterns with random sidelobe levels. This method can be used for designing both linear as well as circular apertures. The resulting patterns also possessed low directivity loss low mutual coupling problem. Several synthesis techniques were described Elliot [13] for getting inputs that result in required radiation patterns. Using these techniques, both sum and difference patterns with scattered deep nulls can be generated from both linear and circular arrays. Aperture distributions, for turned ON elements of huge thinned circular arrays with diameters between 25 to 133.3λ, for producing difference as well as sum patterns were given by Keizer in [14]. Iterative Fourier Transform method is made use of for yielding patterns with low sidelobes. Although several works were reported in open literature for synthesizig difference patterns with low sidelobe taper, it is worth to mention that very limited literature is available on generation of difference patterns from thinned CCA of dipoles.

Optimized difference patterns for different lengths of linear arrays were generated using DE algorithm in [15]. In the present work, dipole antenna arrays are thinned and an amplitude distribution is designed for ON elements to yield low sidelobe difference patterns. The optimum amplitudes and thinning coefficients are derived using Differential Evolution algorithm.

II. DIFFERENTIAL EVOLUTION ALGORITHM

Differential Evolution (DE) is a population based stochastic, optimization technique. It is an effective and proficient global optimizer in continuous search domain. Any practical optimization technique should have three characteristics namely finding true global minimum, faster convergence and few control parameters. Differential Evolution algorithm has all these features. It was first proposed by Storn and Price [16]-[17]. It is a powerful search technique which is successfully applied in many fields like mechanical engineering, communications, pattern recognition etc.

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The algorithm offers following advantages:

- It can easily handle non-linear, non-differentiable complex fitness functions.
- It is a parallel search technique which searches the solution space from different points.
- It offers a way of solving the problem without using its gradient.
- It has the capability to find true global minima regardless of the initial parameter values.
- It has few easy to choose as well as robust control parameters which influence the convergence of the algorithm.
- Good convergence speed in finding optimum value.

A key advantage which prompts the antenna array designers to go for DE is its high computational efficiency which allows the optimum design of large antenna arrays.

In DE, the candidate solutions are called vectors. The important feature that makes a DE algorithm different from other population based techniques is differential mutation operator and trial parameter vectors. The algorithm initially takes samples at random, multiple locations from the objective function. The initial population vectors are generated according to the prefixed parameter bounds. For performing an efficient exploration of the solution space, DE employs a difference between the parameter vectors. The vectors are iteratively updated. New vectors are generated by altering existing vectors. DE performs this by taking the scale difference of two randomly chosen vectors from the initial population. These newly generated vectors compete with the initial population vectors of same index. These undergo fitness evaluation, if they result in better fitness compared to parent vectors, these survivors will act as parents for next generation. The process continues till the convergence criterion is met. The solution with best fitness is taken as the optimum solution.

III. PROBLEM FORMULATION

A 'm' ring CCA of dipoles is shown in figure 2. Here r_m indicates radius of m^{th} ring, N_m indicates the number of dipoles in m^{th} ring and d_m is the interelement spacing where m=1,2,…M.

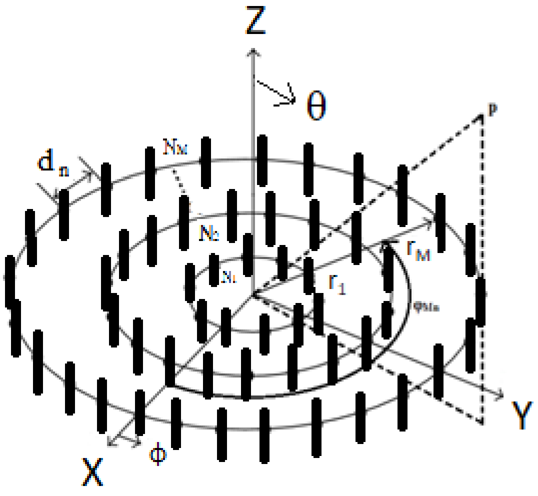

Fig. 1.Geometry of concentric circular array of dipoles

The generalized expression for the array factor [17] is given by

$$E(\theta,\varphi) = \sum_{m=1}^{M}\sum_{n=1}^{N_m} I_{mn}\,\mathrm{A_{mn}}\exp(jk\,r_m \sin\theta\cos[(\varphi-\varphi_{mn})]) \tag{1}$$

Here

M = number of rings

N_m = number of elements in ring m

A_{mn}= Amplitude excitation of n^{th} element of m^{th} ring

I_{mn} = excitation of n^{th} element of m^{th} ring$= \begin{cases} 1 & ON \\ 0 & OFF \end{cases}$

r_m = radius of ring 'm'

φ_{mn} = angular position of n^{th} element of m^{th} ring

$$= \frac{2\pi(m-1)}{N_m} \tag{2}$$

$k = \frac{2\pi}{\lambda}$

θ = elevation angle

φ = Azimuthal angle

In 'u' domain

$$E(u)\,|_{\varphi=constant} = \sum_{m=1}^{M}\sum_{n=1}^{N_m} I_{mn}\,A_{mn}\exp\,(jkr_m\,u\cos(\varphi-\varphi_{mn}))$$

here u=sin(θ)

The expression for radius of m^{th} ring is given by

$$r_m = m\frac{\lambda}{2} \tag{3}$$

The spacing between two adjacent elements is assumed to be nearly $\frac{\lambda}{2}$ i.e. $d_m = \frac{\lambda}{2}$.

The number of equally spaced elements present in ring 'm' is given by $N_m=8*m$ (4)

All the elements have uniform excitation phase of zero degrees. For attaining the difference patterns, half the array must be excited in out of phase. Hence the resultant expression for the array factor is given by

$$AF1(u) = |E_1(u) - E_2(u)| \tag{5}$$

where

$$E_1(u) = \sum_{m=1}^{M}\sum_{n=1}^{N_{m}/2} I_{mn}\,\mathrm{A_{mn}}\exp\,(jkr_m u\cos(\varphi-\varphi_{mn}))$$

and

$$E_2(u) = \sum_{m=1}^{M}\sum_{n=\left(\frac{N_m}{2}+1\right)}^{N_m} I_{mn}\,\mathrm{A_{mn}}\exp\,(jkr_m u\cos(\varphi-\varphi_{mn}))$$

In the above equations, φ is assumed to be 0°.

Now the field equation for dipole antenna is given by

$$AF2 = \frac{\cos\left(\frac{kl}{2}\cos\theta\right) - \cos\left(\frac{kl}{2}\right)}{\sin\theta} \tag{6}$$

Where l=λ/2

The total array factor now becomes

$$AF = AF1 * AF2 \tag{7}$$

IV. METHOD OF SIDELOBE REDUCTION

It is possible to generate patterns with reduced sidelobe levels by exciting ring elements non-uniformly. Thinning is another method for sidelobe level reduction. Both techniques are made use of in this paper for getting optimum results.

The optimum results are found using DE algorithm.

The objective function which is to be minimized for finding the optimum solution is as follows:

$$Fit = w1 * (PSLL_o - SLL_d) + w2 * (FF_o - FF_d) \qquad (8)$$

where

$$PSLL_o = Max\left[20\log\left|\frac{AF(u)}{AF_{Max}(u)}\right|\right]$$

= Obtained Peak Sidelobe level

u ϵ side lobe region.

SLL_d =Desired Sidelobe level

$AF_{max}(u)$= Main beam peak value

FF_o is the obtained Fill factor, FF_d is the desired Fill factor. Fill factor is defined as the number of turned on elements divided by total number of elements present. ‘w1’ and ‘w2’ are weighing factors for controlling the amount of significance given to each term in eq.(8).

V. RESULTS

This section presents the results obtained for a 6 ring CCAA and 7 ring CCAA using the problem defined above. Fig. 2 depicts the radiation pattern for a 6 ring CCAA. The peak SLL obtained is -20.2376dB. The total number of ‘ON’ elements is 88 out of 168 total number of elements. The Fill Factor in this case is 52.38%. The element layout is shown in fig. 3. A ‘o’ symbol indicates an ‘OFF’ element and a ‘*’ symbol indicates an ‘ON’ element. Table I and II present the radii of each ring and amplitude excitations of elements in each ring respectively.

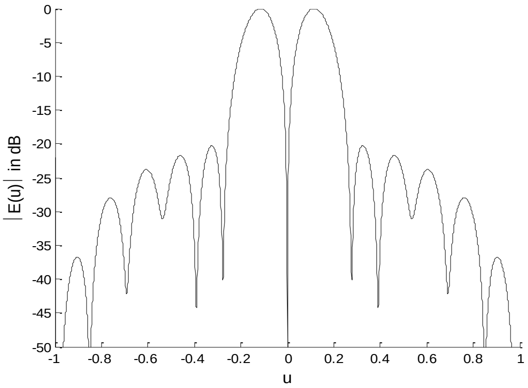

Fig. 2.Radiation pattern for a 6 ring CCAA

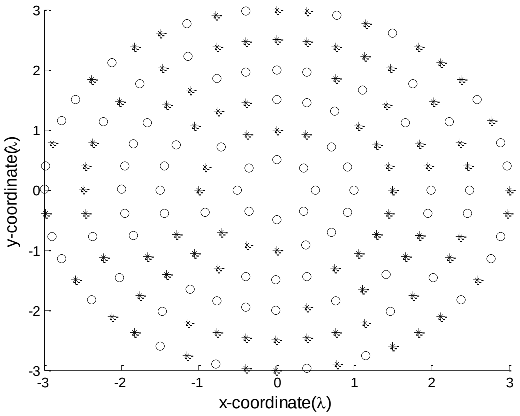

Fig. 3.Geometry of concentric circular array of dipoles

Table- I: Ring radii and number of elements per ring for 6 ring CCAA

Ring number	Radius (wavelengths)	Number of elements in each ring
1	0.5	8
2	1.0	16
3	1.5	24
4	2.0	32
5	2.5	40
6	3.0	48

Table- II: Element excitations of each ring for a 6 ring CCAA

Ring Number	Excitation values
1	-0.899,-0.100,-0.102,-0.385,0.385,0.102,0.100,0.899,
2	-0.805,-0.768,-0.818,-0.519,-0.841,-0.671,-0.285, 0.100, 0.100,0.285,0.671,0.841,0.519,0.818,0.768, 0.805,
3	-0.637,-0.100,-0.774,-0.716,-0.100,-0.897,-0.449, -0.714,-0.872,-0.751,-0.549,-0.409,0.409,0.549, 0.751,0.872, 0.714,0.449, 0.897,0.100,0.716,0.774, 0.100,0.637,
4	-0.900,-0.855,-0.793,-0.866,-0.797,-0.855,-0.824, -0.801,-0.696,-0.157,-0.348,-0.894,-0.879,-0.862, -0.230,-0.871, 0.871,0.230,0.862,0.879,0.894, .348,0.157,0.696, 0.801, 0.824,0.855,0.797, 0.866, 0.793,0.855,0.900,
5	-0.831,-0.149,-0.563,-0.113,-0.100,-0.899,-0.197, -0.100,-0.890,-0.880,-0.100,-0.846,-0.706,-0.679, -0.840,-0.650,-0.813,-0.663,-0.169,-0.835,0.835, 0.169,0.663,0.813, 0.650,0.840,0.679,0.706, 0.846, 0.100,0.880,0.890,0.100,0.197,0.899,0.100,0.113, 0.563,0.149,0.831,
6	-0.780,-0.383,-0.841,-0.809,-0.243,-0.471,-0.219, -0.874,-0.853,-0.880,-0.106,-0.897,-0.900,-0.505, -0.100,-0.893,-0.212,-0.749,-0.145,-0.900,-0.891, -0.868,-0.899,-0.875, 0.875,0.899,0.868,0.891,0.900, 0.145,0.749,0.212,0.893,0.100,0.505,0.900,0.897, 0.106,0.880,0.853,0.874,0.219, 0.471,0.243,0.809, 0.841,0.383,0.780,

Fig. 4 portrays the radiation pattern for a 7 ring CCAA. The peak SLL obtained in this case is -20.5898dB. Fig. 5 shows the corresponding element layout. The Fill Factor in this case is 50%. Table III and IV represent the ring radii and element excitations respectively.

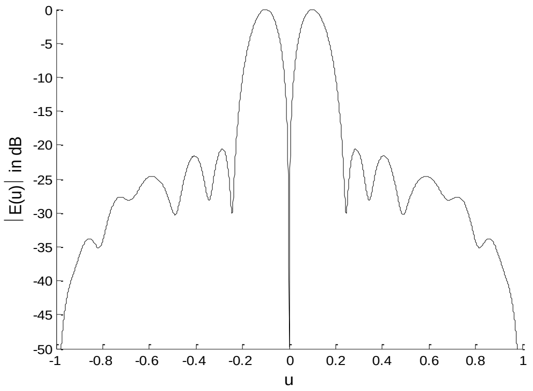

Fig. 4.Radiation pattern for a 7 ring CCAA

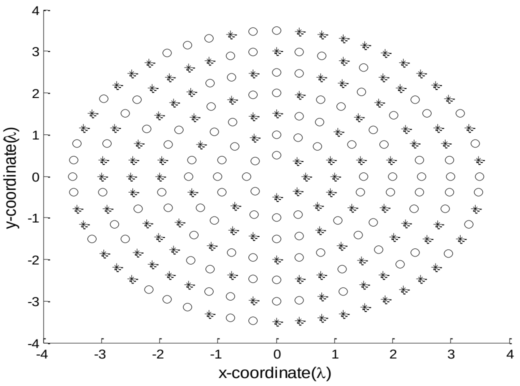

Fig. 5.Element layout for a 7 ring CCAA

Table- III: Ring radii and number of elements per ring for 7 ring CCAA

Ring number	Radius (wavelengths)	Number of elements in each ring
1	0.5	8
2	1.0	16
3	1.5	24
4	2.0	32
5	2.5	40
6	3.0	48
7	3.5	56

Table- IV: Element excitations of each ring for a 7 ring CCAA

Ring Number	Excitation values
1	-0.101,-0.885,-0.885,-0.752,0.752,0.885,0.885,0.101,
2	-0.100,-0.864,-0.105,-0.100,-0.652,-0.875,-0.899, -0.895, 0.895,0.899,0.875,0.652,0.100,0.105, 0.864, 0.100,
3	-0.101,-0.809,-0.100,-0.497,-0.801,-0.874,-0.897, -0.552,-0.102,-0.820,-0.777,-0.900,0.900,0.777,0.820, 0.102,0.552,0.897,0.874,0.801,0.497,0.100,0.809, 0.101,
4	-0.652,-0.206,-0.900,-0.731,-0.103,-0.204,-0.900, -0.899,-0.766,-0.216,-0.761,-0.295,-0.607,-0.674, -0.108,-0.392, 0.392,0.108,0.674, 0.607,0.295,0.761, 0.216,0.766,0.899, 0.900,0.204,0.103,0.731,0.900, 0.206,0.652,
5	-0.154,-0.330,-0.668,-0.100,-0.406,-0.819,-0.855, -0.281,-0.809,-0.326,-0.851,-0.900,-0.834,-0.208, -0.826,-0.139,-0.100,-0.303,-0.100,-0.899,0.899, 0.100,0.303,0.100, 0.139,0.826,0.208,0.834,0.900, 0.851,0.326,0.809,0.281, 0.855,0.819,0.406,0.100, 0.668,0.330,0.154,
6	-0.280,-0.100,-0.208,-0.514,-0.114,-0.393,-0.156, -0.695,-0.899,-0.673,-0.101,-0.900,-0.439,-0.614, -0.796,-0.845,-0.100,-0.899,-0.868,-0.496,-0.217, -0.268,-0.363,-0.899,0.899,0.363,0.268, 0.217,0.496, 0.868,0.899,0.100,0.845,0.796,0.614,0.439,0.900, 0.101,0.673,0.899,0.695,0.156, 0.393,0.114,0.514, 0.208, 0.100,0.280
7	-0.888,-0.748,-0.777,-0.427,-0.245,-0.238,-0.467, -0.256,-0.771,-0.102,-0.531,-0.620,-0.100,-0.896, -0.898,-0.163,-0.899,-0.518,-0.723,-0.123,-0.101, -0.689,-0.186,-0.662,-0.133,-0.857,-0.702,-0.226, 0.226,0.702,0.857,0.133, 0.662,0.186,0.689,0.101, 0.123,0.723,0.518,0.899,0.163, 0.898,0.896,0.100, 0.620,0.531,0.102,0.771,0.256,0.467, 0.238,0.245, 0.427,0.777,0.748,0.888

VI. CONCLUSION

Difference patterns are generated in general by using linear arrays owing to their simplicity. Concentric circular antenna arrays of dipoles are employed in the present work to generate low sidelobe difference patterns. It is evident from the results that the generated difference patterns have lowest possible sidelobes. The number of active elements is also low thus reducing weight and cost. All results are simulated using Matlab software.

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