RESEARCH ARTICLE OPEN ACCESS

Thinning of Elliptical Antenna Arrays Using Genetic Algorithm

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ABSTRACT
Design of thinned elliptical antenna array using Genetic Algorithm (GA) optimization is presented in this paper. The antennas are assumed to be isotropic and are uniformly excited. Thinned arrays produces narrow directive beam without causing major degradation of fully populated antenna arrays. Thinning of elliptical antenna arrays using GA are optimized with different values of eccentricity and the variation of side-lobe level (SLL) with eccentricity is reported. Using GA optimization, reduction of SLL can be obtained by varying the value of eccentricity of elliptic arrays arrangement.
Keywords - Elliptical antenna arrays, genetic algorithm, side-lobe level, thinning.

I. INTRODUCTION

Antenna arrays are a group of antenna elements which are excited to achieve a desired radiation pattern in a given direction. They can provide capability of beam steering. Antenna arrays are widely used in sonar, radar, communication and high power transmission applications [1]. While designing, it is necessary to have control over radiation, orientation, location and excitation current [2]. Antenna radiation pattern consist of a main lobe and unwanted side lobes. The side lobe consumes power and causes interference in undesired direction. A linear array has excellent directivity and can produce narrow main beam in a given direction. But it cannot produce well in all azimuth direction. As circular arrays do not have edge elements so it has not any nulls in azimuth plane [2].Thinning means switching 'off' some active elements to create a desired amplitude density across the aperture. Elements connected to feed network are 'on' and 'off' are connected to dummy load or open circuit. Purpose of thinning is to produce low side lobes [3]. Various thinning methods are available to reduce SLL, such as, thinning based on empirical or analytical formula [4], space or density tapering [5,6], statistically thinned arrays [7], optimizing technique etc.

[3, 8-10]. When many antenna elements are arranged in the form of ellipse it is called elliptical arrays. The geometry of elliptical array is shown in Fig.1. In Fig.1, 'a' and 'b' are semi-major axis and semi-minor axis respectively and eccentricity of ellipse is given by e=$\sqrt{(1-a^2/b^2)}$.

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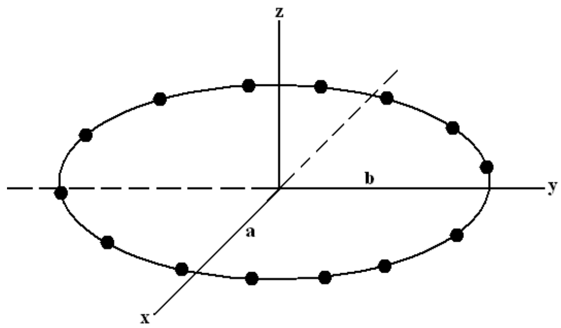

Fig.1. Geometry of elliptical antenna array

Since, computers are so computationally fast these days, thinning and placement optimization are often done via optimization algorithm like genetic algorithm, particle swarm optimization, differential evolution, invasive weed optimization, simulated annealing etc [11-14]. Elliptic configuration has one extra parameter like 'eccentricity' which is absent in circular configuration. Due to eccentricity, SLL can be reduced more as compared to circular arrays.

In this paper, GA optimization is used to minimize SLL in a thinned array design without degrading the system performance significantly. Also, investigation of optimized thinned elliptic array with various eccentricities is presented in this paper. Reports on optimized thinned elliptical antenna arrays are less compared to linear, planar, circular and concentric circular arrays. Optimized results are compared with fully populated arrays.

II. GENETIC ALGORITHM

Genetic algorithm is a iterative stochastic optimization method that work on the concept of survival of fittest. GA search from many points instead of single point. They don't use derivatives and work on random transition rules instead of deterministic rules [15]. In this paper, programming for GA is done using MATLAB coding. A flowchart of GA is shown in Fig.2.

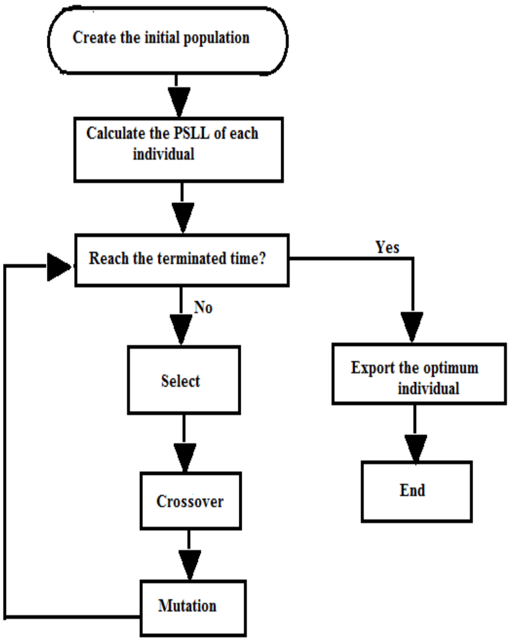

Fig.2. Flowchart for GA optimization

The thinning and optimization approach is shown in the following:

Step 1: The rightmost element of array is considered as start point. Rest of the elements are encoded along counter clockwise. When an element in some position is kept 'off', it is encoded as '0', otherwise 'on' elements are encoded as '1'. Hence, antenna arrays are encoded as binary code.

Step 2: Create a population size i.e., the number of individuals or chromosomes considered in one generation.

Step 3: Peak side lobe level (PSLL) of each individual is calculated. The fitness function is designed as: fitness=PSLL.

Step 4: Selection procedure- The selection of population is according to the fitness of individuals. Individuals possessing high fitness value have a priority for remaining to the next generation. Otherwise it will be discarded. A new generation is produced. There are many strategies like roulette-wheel, tournament, rank selection etc.

Step 5: Crossover- The chromosomes of population were coupled randomly and the paired chromosomes cross at some point. Crossover may be single point, two points, uniform, half -uniform cross over.

Step 6: Mutation: This operator modifies bit string in a single individual using random change. A new population is generated.

Step 7: Iteration- Fitness value of each individual in the new population is calculated and then the best and the worst solution are found. The worst solution is replaced with the best one.

Steps are repeated until it meets the stopping criteria and optimal solution appears.

III. ELLIPTICAL ARRAY THINNING USING GA

In this paper, four cases of elliptical arrays are considered with element number 40, 100, 140 and 200. Inter element spacing is kept constant and eccentricity is varied for each case. The SLL is defined as SLL(dB)=$20\log_{10}$(amplitude of side-lobe/ amplitude of main lobe). SLL changes with different 'on' and 'off' condition of antenna elements. The maximum amplitude of SLL for particular combination is termed as SLL_{max}. GA optimization is applied to achieve minimum SLL, min(SLL_{max}) for each case. The overall radiation pattern changes when many antenna elements are combined together in an array [16]. This is due to the array factor (AF) which quantifies the effect of combining radiating element without taking a specific radiation pattern into account. If the value of AF is large, all isotropic sources radiate high level of power, which leads to interference [2, 17]. GA is used to control the positions on 'on' and 'off' elements in the elliptical array [18]. Overall radiation pattern of array antenna is given by array factor (AF) multiplied with radiation pattern of antenna [1, 2]. The geometry of elliptical array with co-ordinate system is presented in Fig. 3.

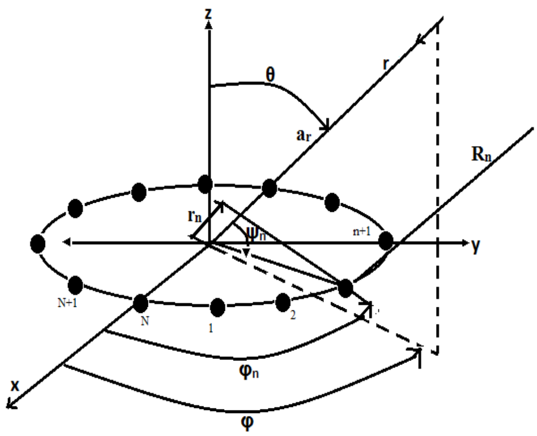

Fig.3. Geometry of ellipse in XY-plane

In XY plane, the array far field function for Elliptic array is given by:

$$E(r, \varphi, \theta) = \sum_{n-1}^{N} a_n \frac{e^{-j\beta R_n}}{R_n} \quad (1)$$

$$R_n = r - \sin\theta(x\cos\varphi_n a_x + y\sin\varphi_n a_y) \quad (2)$$

When centre of the ellipse lie at the origin on x-y plane, the rectangular co-ordinate system equation of ellipse is given by:

$$x = a\cos\varphi \quad (3)$$

$$y = b\sin\varphi \quad (4)$$

Where, φ is the azimuth angle measured from positive x-axis and θ is the elevation angle measured form positive z-axis.

Also eccentricity e of an ellipse is defined as:

$$e = \frac{c}{a} = \sqrt{1 - \frac{b^2}{a^2}} \quad (5)$$

$$c = \sqrt{a^2 + b^2} \quad (6)$$

Where, c is the half of the distance between two focus, when centre lie at the origin of x-y plane.

So, the equation of an ellipse becomes:

$$R_n = r - \sin\theta(a\cos\varphi\cos\varphi_n a_x + b\sin\varphi\sin\varphi_n a_y) \quad (7)$$

Where, $\varphi_n = \frac{2\pi(n-1)}{N}$ (8)

is the angular position of the n-th element in x-y plane.

Generally, Array Factor of ellipse can be written as:

$$AF(\theta,\varphi) = \sum_{n=1}^{N} A_n e^{j(\alpha_n + kR_n . a_r)} \quad (9)$$

$$a_r = \sin\theta\cos\varphi\, a_x + \sin\theta\sin\varphi\, a_y + \cos\theta\, a_z \quad (10)$$

Here, N is the number of antenna in a array, A_n is the excitation amplitude of n-th element, α_n is the relative phase of n-th element of array, R_n is the position vector, a_r is the unit vector and k is a wave number.

Substituting Eq. (7) & Eq. (10) in Eq. (9), Array Factor of elliptical array can be expresses as:

$$AF(\theta,\varphi) = \sum_{n=1}^{N} A_n(\exp(jk\sin\theta(a\cos\varphi_n \cos\varphi + b\sin\varphi_n \sin\varphi))) \quad (11)$$

IV. OPTIMIZED RESULTS

Inter-element spacing and eccentricity is kept constant at d=0.3λ and e = 0.6 respectively in all the cases in optimization. The value of k for all elliptical arrays is 6.75 m^{-1}, that is, frequency is 322.45MHz.

GA optimized result for 40 element thinned elliptic array is compared with fully populated elliptic array in Fig. 4. Minimum SLL for fully populated array is given by -8dB and for GA optimized thinned array, SLL is given by -15.1dB. Here, the number of 'on' elements is 20, filled ratio is 50%.

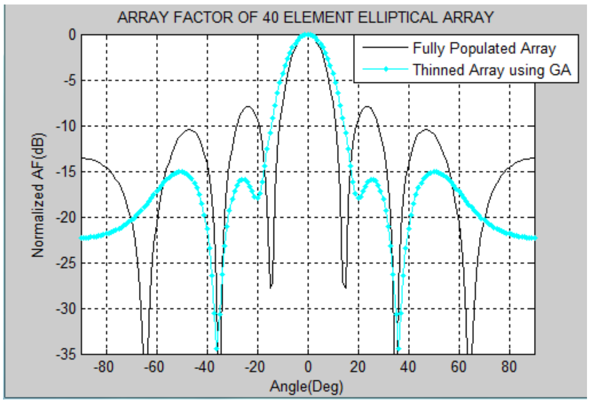

Fig.4. Array factor for 40 element elliptic array

GA optimized results for 100 elements thinned elliptic array is compared with fully populated elliptic array in Fig.5. Minimum SLL for fully populated array is given by -8dB and for GA optimized thinned array, minimum SLL is given by -15.24dB. Here, number of 'on' elements is 51, filled ratio is 51%.

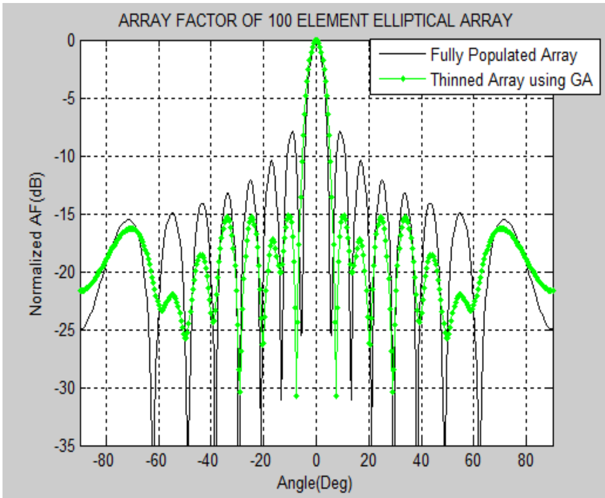

Fig.5. Array factor for 100 element elliptic array

GA optimized result for 140 elements thinned elliptic array is compared with fully populated elliptic array in Fig.6. Minimum SLL for fully populated array is given by -8dB and for GA optimized thinned elliptic array, minimum SLL is given by -10.21dB. Here, number of 'on' elements is 62, filled ratio is 44.28%.

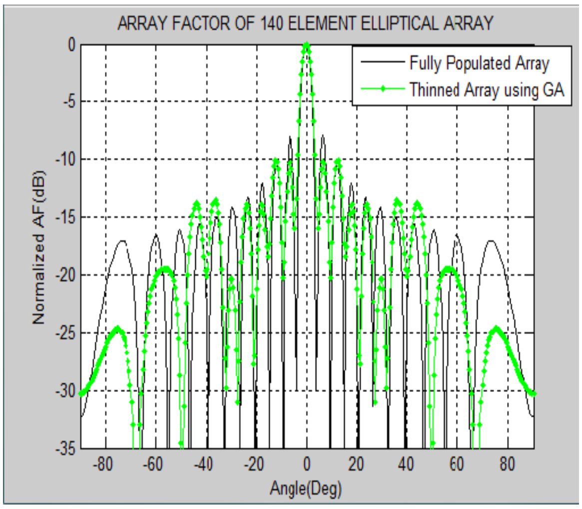

Fig.6. Array factor for 140 element elliptic array

GA optimized result for 200 element thinned elliptic array is compared with fully populated elliptic array in Fig.7. Minimum SLL for fully populated elliptic array is given by -8.4dB and for thinned elliptic array, minimum SLL is given by -10.58dB. Here, the number of 'on' elements is 98, filled ratio is 49 %.

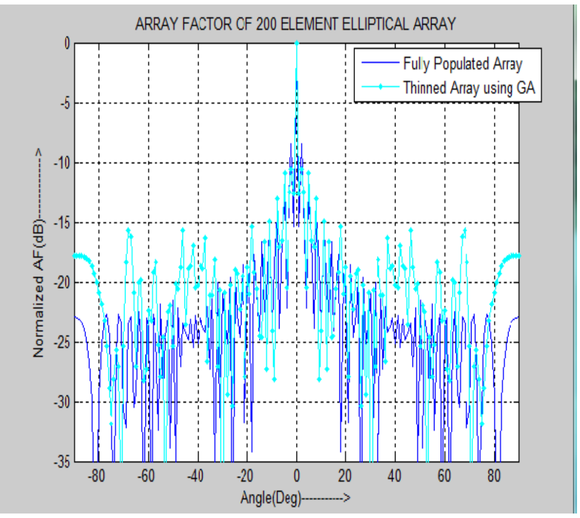

Fig.7. Array factor for 200 element elliptic array

Variations of minimum SLL with eccentricity are tabulated in Table 1.

Eccentricity	e = 0.4	e = 0.5	e =0.6	e = 0.7	e = 0.8
N = 200	SLL_{max} = -10.02dB	SLL_{max} = -11.12dB	SLL_{max} = -15.58dB	SLL_{max} = -10.32dB	SLL_{max} = -9.76dB
N = 140	SLL_{max} = -10.23dB	SLL_{max} = -10.13dB	SLL_{max} = -10.15dB	SLL_{max} = -10.17dB	SLL_{max} = -10.1dB
N = 100	SLL_{max} = -15.14dB	SLL_{max} = -15.15dB	SLL_{max} = -15.17dB	SLL_{max} = -15.15dB	SLL_{max} = -15.16dB
N = 40	SLL_{max} = -15.1dB	SLL_{max} = -15.1dB	SLL_{max} = -15.1dB	SLL_{max} = -15.1dB	SLL_{max} = -15.2dB

Table.1. Comparison of maximum SLL between arrays by varying eccentricity where spacing is fixed at d = 0.3λ.

V. CONCLUSION

Inter-element spacing between antennas is kept uniform, but, when thinning is applied, due to some 'off' elements, the spacing becomes non-uniform. Also, due to change in eccentricity parameter, 'on', 'off' arrangement of ellipse varies. When eccentricity is increased, the distance between the array components decreases which help to reduce side lobe level but enhances the main lobe beam-width. On the other hand, on decreasing the value of eccentricity better directivity is obtained with reduced main lobe beam-width. A good reduction in SLL is obtained in all the cases. But, inter-element spacing is not varied. Attention is paid only to find the optimum position of array to reduce SLL.

REFERENCES

[1] A. S. Zare, " Elliptical antenna array pattern synthesis with fixed side lobe level and suitable main beam beam-widthby Genetic algorithm", *Majlesi Journal of Telecommunications Devices Vol. 1, No. 4, pp-113-120*, December 2012.

[2] A. A. Lotfi, M. Ghiamy, M.N. Moghaddasi, R. A. Sadeghzadeh, "An Investigation of Hybrid Elliptical Arrays, *Iranian Journal Of Electrical And Computer Engineering, Vol. 7, No. 2,pp-98-106*, Summer-Fall 2008.

[3] R. L. Haupt, "Thinned Arrays Using Genetic Algorithms," *IEEE Trans. Antennas and Propagation, vol.42, no. 7, pp. 993-999*, 1994.

[4] S. J. Blank and M. F. Hutt, "On the Empirical Optimization of Antenna Arrays," *IEEE Antennas and Propagation Magazine, vol. 47, issue 2, pp. 58-67*, April 2005.

[5] W.P.M. N Keizer, "Synthesis of Thinned Planar Circular and Square Arrays using

Density Tapering", *IEEE Transaction on Antenna and Propagation, issue 99, pp-1-8,* 2013.

[6] M.I. Skolink, J. W. Sherman, "Statistically Designed Density-Tapered Arrays", *IEEE Transactions on Antennas and Propagation, vol.12, issue 4, pp-408-417,* July 1964.

[7] R. J. Mailloux, E. Cohen, "Statistically Thinned Arrays with Quantized Element Weights", *IEEE Transactions On Antennas And Propagation, Vol. 39, No.* ***4,*** *pp-436-447,* April 1991.

[8] K. K. Yan, Y. Lu, "Side-lobe Reduction in Array-Pattern Synthesis Using Genetic Algorithm", *IEEE Transactions on Antennas and Propagation, Vol. 45, No. 7,pp-1117-1122,* July 1997.

[9] V. Shreni, P. Raikwar, "Optimization of Reduction in Side Lobe Level Using Genetic Algorithm", *IJETAE Volume 2, Issue 12, pp-202-205,* December 2012.

[10] D. Marcano, F. Duran, "Synthesis of Antenna Arrays Using Genetic Algorithms", *IEEE Antennas and Propagation Magazine, Vol. 42, No. 3, pp-12-20,* June 2000.

[11] P. Ghosh, S. Das,"Synthesis of Thinned Planar Concentric Circular Antenna Arrays - A Differential Evolutionary Approach", *PIER B, vol. 29, pp. 63-82,* 2011.

[12] A. Mandal, S. Das,, "Design Of Dual Pattern Concentric Ring Array Antenna Using Differential Evolution Algorithm With Novel Evolutionary Operators", *Progress In Electromagnetic Research M, Vol. 22, 163-178*, 2012.

[13] R. Bera, J. S. Roy, "Thinning of Elliptical and Concentric Elliptical Antenna Arrays Using Particle Swarm Optimization", *Microwave Review vol.19, no. 1, pp-2-7,* Sept. 2013.

[14] S. Pal, A. Basak, S. Das, A. Abraham, I. Zelinka, "Circular Antenna Array Synthesis Using a Differential Invasive Weed Optimization Algorithm", *IEEE Conference, pp-395-400,* 2010

[15] David E. Goldberg, Genetic algorithm in search, optimization & machine learning (Dorling Kindersley, India, 1989).

[16] A. A. Noaman, Dr. A. Kareem, S. Abdallah, Dr. R. S. Ali, "Optimal Sidelobes Reduction and Synthesis of Circular Array Antennas Using Hybrid Adaptive Genetic Algorithms", *IEEE MIKON, pp-1-4,* 2010.

[17] C. Ding, L. Jianxin,"GA Design of Large Thinned Arrays", *IEEE Antenna and Propagation Conference, pp-492-494,* 2009.

[18] A. Lotfi Neyestanak, M. Ghiamy, M. Naser-Moghaddasi and R.A. Saadeghzadeh,"Investigation of hybrid elliptical antenna arrays", *IET Microwave. Antennas Propagation. 2, (1), pp. 28–34,* 2008.