DESIGN OF LINEAR DIPOLE ARRAY ANTENNA USING HYBRID PSO-GSA OPTIMIZATION TECHNIQUE

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Abstract

This project presents an application of nature inspired population based algorithm namely particle swarm optimization-Gravitational Search Algorithm (PSOGSA) to Linear Dipole Antenna Array (LDAA) optimization. The design parameters of the LDAA to be optimized are the length of the dipole antenna elements and spacing's out of each of the group of two neighbor elements. The PSO-GSA using MATLAB is used to optimize the design parameters of the LDAA to determine a set of performance parameters of LDAA such as directivity and side lobe level. The major goal of antenna design is to achieve narrow beamwidth (high directive gain) and low side lobe level. The optimized radiation patterns indicate that the application of the PSOGSA to our optimization problem is found to be a promising one for obtaining a higher directivity and lower side lobe level. The results obtained show the effectiveness of PSOGSA and is implemented using matlab tool.

1. Introduction

Adaptive Beamforming (ABF) is used in a wide variety of different areas, such as radar, sonar, communication, radio ast-ronomy and medical. Basically, ABF algorithms have gained wide attention by researcher's community due to the wider ra-nge of application. MVDR or Capon beamformer [1] is one of the optimum statistical beamformers which assures a distortio-nless response for a predefined steering direction [2]. The b-asic idea of the MVDR technique is to estimate the excitation coefficients in an adaptive manner by minimizing the variance of the residual interference and noise while enforcing a set of linear constraints to ensure that the real user signal is not dist-orted [3]. MVDR weight vector solution depends on the array response vector and the estimation of the covariance matrix of user-of-interest (UOI) signals and user-not-of-interest (UNOI) sources. The null-forming for MVDR has poor SINR output due to low null level towards the UNOI signals when multiple access interference is existing [4], the finite size of data snapshots [5] or the array response vector uncertainty [6].

There are many ways to make the MVDR beamformer robust against this error such as diagonal loading [7] or beamspace processing [8]. This empirical framework does not always lead to a solution that is easily identifiable. Therefore, optimization methods can be applied to provide a robust solution for the smart antenna system. Some researchers have presented numerical techniques involving nature-inspired optimization to improve the antenna beampattern, beamwidth, sid elobe control, phase shifter, or complex weight vector based conventional beamforming techniques [9]. Heuristic optimization algorithms are used widely to solve many engineering problems. For example, in [4] combined the MV DR with PSO and GSA algorithm. The results show that the proposed GSA performance is better than the performance of the PSO and MVDR algorithms. Unfortunately, the effects of population size and a number of maximum iteration also not explicitly mentioned and investigated. Thus, the solution of this study is not the most accurate one. Null steering (NS) techniques have been used extensively for interference suppression purposes in communication. In NS algorithms, the weights of an antenna array are selected such that the directional pattern has nulls in particular directions. In this manner, undesirable interference, jamming signals, or nois-e can be reduced or eliminated.

A single element antenna is usually not a good choice to achieve technical needs because of its limited performance. The E and H plane patterns of a single antenna are very wide and hence provide a low value of directivity [10]. In most of the applications, it is essential to design an antenna with a high directivity to fulfill the demand for distant communication. In antenna design, it is frequently desirable to achieve both narrow beamwidth and low side lobe level. To

achieve the above characteristics a Linear Dipole Antenna Array(LDAA) may be used.

The minimization of side lobe level (SLL) assures that the receiving or radiating energy to be directed in a particular direction. The above desired characteristics of low SLL and narrow beamwidth oppose one another as the array with smallest beamwidth does not provide low SLL and array with the smaller SLL slightly increases the beamwidth [11]. Hence,it is difficult to achieve both the characteristics simultaneously using a LDAA. In fact the lower beamwidth in the main lobe of the radiation pattern indicates higher directivity (D). A LDAA with uniform lengths, spacings, and excitation amplitude does not provide desired narrow beamwidth and low SLL. But a LDAA with non-uniform lengths, spacings,and excitation amplitude may provide desired narrow beamwidth and low SLL. Here in case of a LDAA, the design parameters are lengths of the dipole antenna elements and spacings obtained from the group of two near by dipole antenna elements. The performance parameters of the same LDAA are D and SLL. The dipole antenna elements of the LDAA considered in this paper are fed by an excitation with uniform amplitude and phase.

In many literatures, various optimization techniques are applied to different linear array antennas. Some of the examples among them are Direction of Arrival (DOA) estimation method based on maximum likely hood criteria for uniform circular array of 12 elements using Gravitational Search Algorithm (GSA), which shows better performance over Particle Swarm Optimization (PSO) and Multiple Signal Classification (MUSIC) algorithm [12]. GSA is a nature inspired population based search algorithm used for solving various nonlinear functions in highly dimensional search space [13]. In planar ultra wide band antenna with irregular shape radiator are designed using GSA which showsbetter performance results over Central Force Optimization (CFO) algorithm [14]. In most cases GSA provides superior or at least comparable result with PSO and CFO. In this paper PSO and GSA are combined and resulted are evaluated.

2. Linear antenna array

Linear antenna array (LAA) is one of the easiest array antennas in implementation and fabrication. Figure 1 shows a linear antenna array that consists of *2N* elements symmetrically distributed along the *x*-axis.

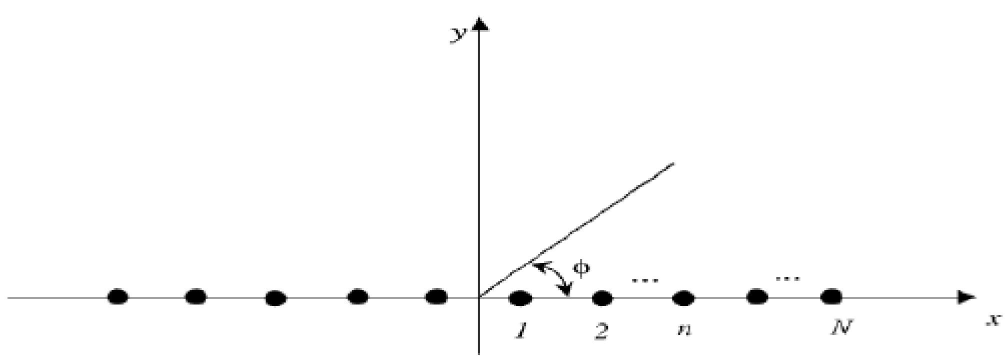

Figure1. Geometry of 2N-element symmetric LAA placed along the x-axis.

In general, the array factor of a LAA is given as follows:

$$AF(\emptyset) = 2\sum_{n=1}^{N} I_n \exp(j[kx_n cos(\emptyset) + \varphi_n]) \quad (1)$$

where k is the wave number, and *In* , φn, and *xn* are, respectively, the excitation amplitude, phase, and location of the array elements. Assuming that the 2N elements are placed symmetrically along the x-axis simplifies the array factor to become as follows:

$$AF(\emptyset) = 2\sum_{n=1}^{N} I_n \cos[kx_n cos(\emptyset) + \varphi_n] \quad (2)$$

In order to minimize the maximum side lobe level (SLL), it is clear from equation (2) that, there are three parameters controlling the array factor; the amplitudes, the phases, and the positions of the elements. In this project, GSA method is used to design LDAAs by optimizing these parameters individually.

Linear Dipole Antenna Array (LDAA)

The analysis of the dipole antenna array mathematically is based on Pocklington's integral equation [1] using method of moment. The equation of current and tangential electric field in the dipole can be written as in (3).

$$\int_{\frac{-L}{2}}^{\frac{L}{2}} I(z')\left(\frac{\partial^2}{\partial z^2}+k^2\right)\frac{e^{-jkR}}{R}dz' = j4\pi\omega\varepsilon_0 E_z^t \quad (3)$$

Where L=length of the one dipole, $I(z')$=line source current,

ω= angular frequency, $k^2 = \omega^2\mu\varepsilon$, $R = [(x-x')^2 + (y-y')^2 + (z-z')^2]^{1/2}$

ε_0 = free space permittivity,

E_z^t= z-component of electric field.

The electric field in total is obtained by summing the field contribution from each radiating dipole [1].

$$E_\theta = \frac{j\omega\mu_0 e^{-jkr}}{r}\sin\theta\sum_{n=1}^{N}\left\{e^{jk(x_n\sin\theta\cos\varphi+y_n\sin\theta\sin\varphi)}\times\sum_{m=1}^{M} I_{nm}\left[\frac{\sin(z^+)}{z^+}+\frac{\sin(z^-)}{z^-}\right]\right\}\frac{L_n}{2} \quad (4)$$

Where μ_0= free space permeability, r=distance between center of the dipole and the point of observation, N=Number of dipole in the array, x_n = x-coordinate of center of the dipole, y_n = y-coordinate of center of the dipole.

$$z^+ = \left[\frac{(2m-1)\pi}{L_n} + k\cos\theta\right]\frac{L_n}{2}$$

$$z^- = \left[\frac{(2m-1)\pi}{L_n} - k\cos\theta\right]\frac{L_n}{2}$$

The electromagnetic interaction among the dipole elements in an LDAA is known as mutual coupling. When the spacing between two elements is large the influence of mutual coupling is negligible, but when the spacing between two elements is small, the influence of mutual coupling is significant. This phenomenon influences the performance parameters of the LDAA. But in our case the lengths of dipoles and spacing between two nearby elements are not equal. This non uniform lengths and spacings are preferred to achieve better performance parameters of the antenna.

However, the diameter of each dipole of LDAA is fixed for simplicity. The field pattern of the array in total is obtained by considering Method of moment equation as in (4).In case of LDAA the separation between the elements, amplitude and phase of the input excitation to the individual elements can be used to shape the overall pattern of the antenna. In our case as mentioned, we have taken a non-uniform LDAA with different lengths and different spacing between elements. An N element LDAA consists of a linear arrangement of N number of dipoles with a (N-1) number of spacings. Thus, the LDAA has (2N-1) number of parameters that determine its performance. The design variables of the N element LDAA are Ln is the length of the n^{th} dipole, d_n is the distance between $n+1^{th}$ and n^{th} element. Here, a 16 element LDAA structure is considered for optimization is as shown in Fig2.

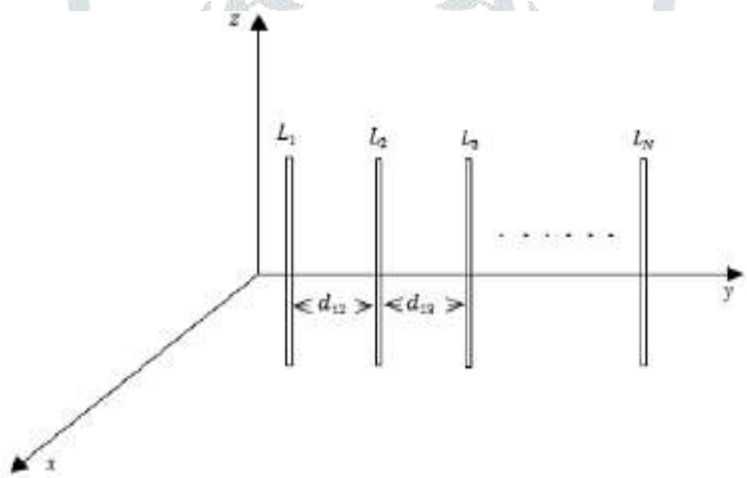

Fig2. N Element LDAA in space

3. Hybrid PSOGSA optimization approach

According to [15], the PSO is hybridized with GSA making use of a small level (combine the functionality), co-evolutionary (parallel running) and assorted (sharing in ultimate outcome-s) hybrid. In this part, hybrid PSOGSA algorithm is introduced and applied to the smart antenna array system to find excitation weight solution more efficiently. The simple idea of PSOGSA is to amalgamate the social thinking skill (the use of *Pgbest*) of PSO algorithm with GSA's local searching ability. The hybrid algorithm mainly integrates the ability of exploration in PSO and the ability of exploration in GSA algorithms, which has a better balance between the ability of exploitation and explorati-on efficiently to find the global optimum. The process of the hybrid algorithm is formulated in detail as follows [15]:

Step1: (Identify the search space). Suppose a system with *N* agents; the algorithm starts with randomly placing all agents in search space.

Step2: (Evaluate the values of the fitness function (*ff*) for the agents; Eq. (5)). All the agents are ranked based on their fitness. The P_{gbest} is the agent with the best fitness value.

Step3: (Computing the gravitational force $F_{ij}^{d}(t)$). The $F_{ij}^{d}(t)$ is the forces from agent *j* on agent *i* at a specific time *t* with *dth* dimension, is defined as follows:

$$F_{ij}^{d}(t) = G(t)[(M_{pi}(t) \times M_{aj}(t)) / (R_{ij}(t) + \varepsilon)](P_{j}^{d}(t) - P_{i}^{d}(t)) \tag{5}$$

where $M_{aj}(t)$ is the active gravitational mass related to agent *j*, $M_{pi}(t)$ is the passive gravitational mass related to agent *i*, ε is a small constant, *G*(*t*) is the gravitational constant at time *t*, and $R_{ij}(t)$ is the Euclidian distance between two agents *i* and *j*,$p_{i}^{d}(t)$, $p_{j}^{d}(t)$ refer to *i* and *j* agents position and the *G*(*t*) is calculated as,

$$G(t) = G_0 \times e^{-\alpha(t/T)} \tag{6}$$

where G_0 is the initial value of the gravitational constant, α a fixed value that the user determines, and *t* is the current iteration, and *T* is the total number of iterations generations.

Step4: (The masses and total force computation). Inertial masses are calculated according to their *ff* value, as follows:

$$M_{ai}=M_{pi}=M_{ii}=M_i; \quad i=1, 2, \ldots, N$$

$$M_i(t) = m_i(t) \Big/ \sum_{j=1}^{N} m_j(t) \tag{7}$$

$$m_i = fit_i(t) - worst(t) / best(t) - worst(t) \tag{8}$$

where $fit_i(t)$ is the fitness of agent *i* at time t. At each generation, the *best* and *worst* of the calculated fitness value is selected for all agents and the improvements are made to maximize the problem defined as:

$$best(t) = \max_{j \in \{1,\ldots,N\}} fit_j(t) \tag{9}$$

$$worst(t) = \min_{j \in \{1,\ldots,N\}} fit_j(t) \tag{10}$$

If the dimension of the problem is *d*, the total force acting on a mass *i* is calculated after calculating the force between two masses as the following equation:

$$F_{i}^{d}(t) = \sum_{\substack{j=1 \\ j \neq i}}^{N} rand_j[0,1] \times F_{ij}^{d}(t) \tag{11}$$

where rand*j* is a random number in the interval [0,1].

Step5: (Computing the agent acceleration). According to the law of motion, the acceleration of an agent is proportional to the resulting force and inverse of its mass; therefore, the acceleration, $a_{i}^{d}(t)$, of the agent *i* at t^{th}generation in d^{th} dimension can be computed as:

$$a_{i}^{d}(t) = F_{i}^{d}(t) \big/ M_{ii}(t) \tag{12}$$

Step6: The velocity and position of agents are calculated as follow:

$$V_{i}^{d}(t+1) = [wV_i(t)] + [c_1 \, rand_1 \, a_{i}^{d}(t)] + [c_2 rand_2 (P_{gbest}^{d}(t) - P_{i}^{d}(t))] \tag{13}$$

$$P_{i}^{d}(t+1) = P_{i}^{d}(t) + V_{i}^{d}(t+1) \tag{14}$$

Where $v_{i}^{d}(t)$ refers to the i^{th} agent's speed at the t^{th} iteration in the d^{th} dimension, *w* is the inertia weighting factor, learning constants *c1* and *c*2 are scaling factors that control the relative pull of P_{gbest}, *rand₁* and *rand₂* are random numbers in the interval of [0, 1], $P_{i}^{d}(t)$ is the present location of the i^{th} particle at the t^{th} iteration

in the d^{th} dimension, P_{gbest} is the best solution found so-far by all the swarm particles, and thus considered to be the optimal resolution at the t^{th} iteration till present.
Step7: Renew the fitness value for all agents by the speed and position of each particle is updated. The fitness values of renewed agents are calculated; then, the process returns to Step 2, repeated until either the maximum number of iteration is reached or the fitness is met.

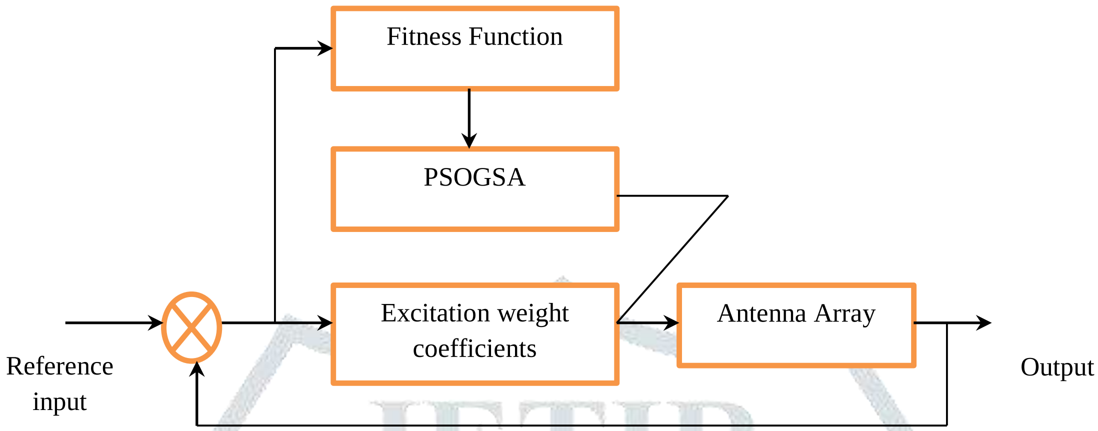

Fig 3. Block diagram of the proposed beamformer with PSOGSA algorithm.

4. Results and Discussion

Initially a random matrix is generated by the PSOGSA code which represents a group of dipole antenna lengths and spacings out of each of the group of two neighbor dipole elements. During the optimization process the set of lengths and spacings are redefined based on the fitness value of the designed LDAA and PSOGSA algorithm. Operating frequency of the LDAA is considered as 300 MHz, so the wavelength is 1 meter and the lengths and spacings are expressed by the fractional multiple of wavelength.

For 19 elements:

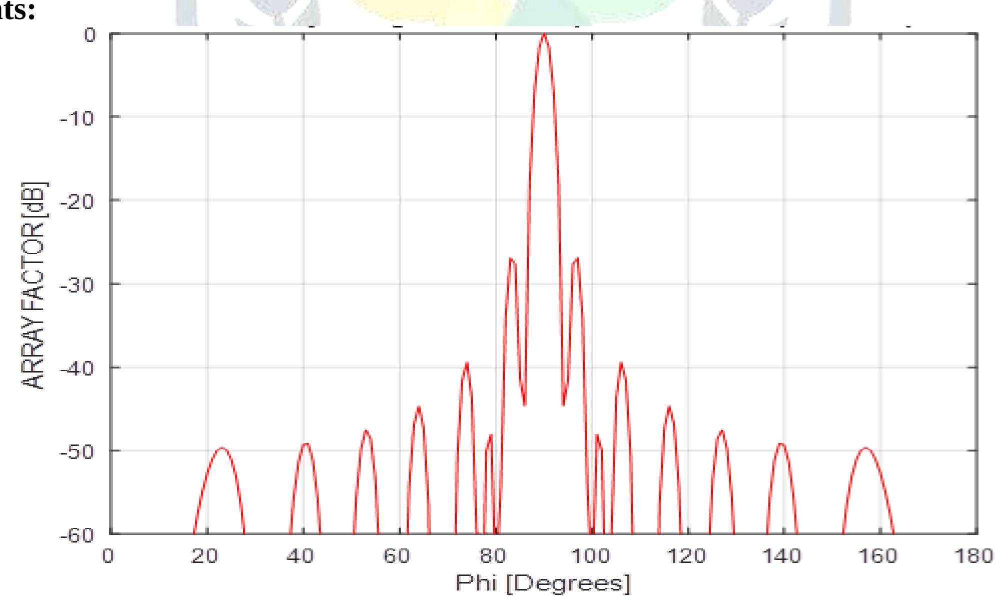

Fig5. LDAA using PSOGSA amplitude optimization

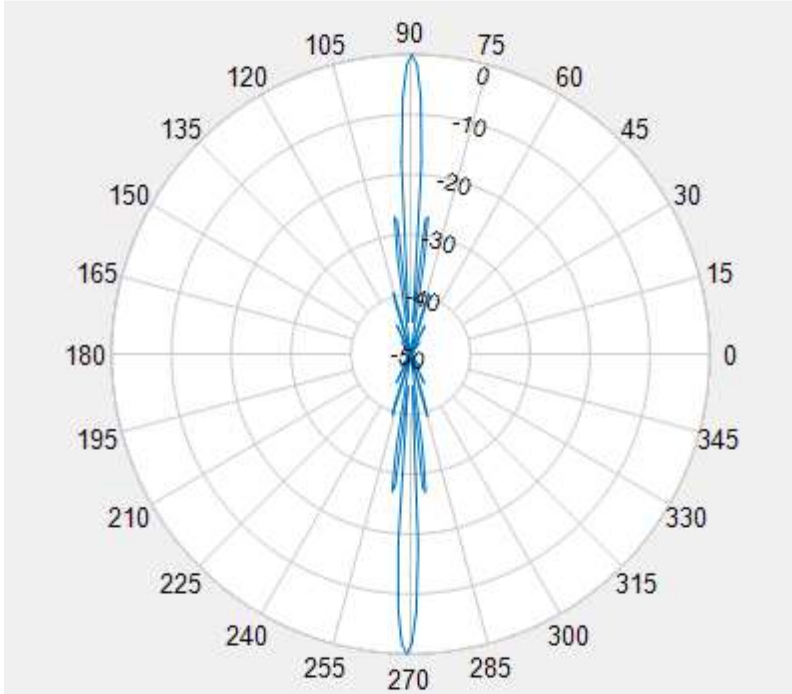

Fig6. Normalized E-plane pattern for optimized 19 element LDAA

When the PSOGSA code is executed, the LDAA code is executed immediately using a CALL from PSOGSA and after execution returns the fitness value of the current design to PSOGSA. The optimization process continues till the iteration criteria are not satisfied. At the end, basing on GSA algorithm a set of lengths and spacings of the LDAA is obtained which give the optimum D and SLL whose values are close to the desired values.

For 18 elements:

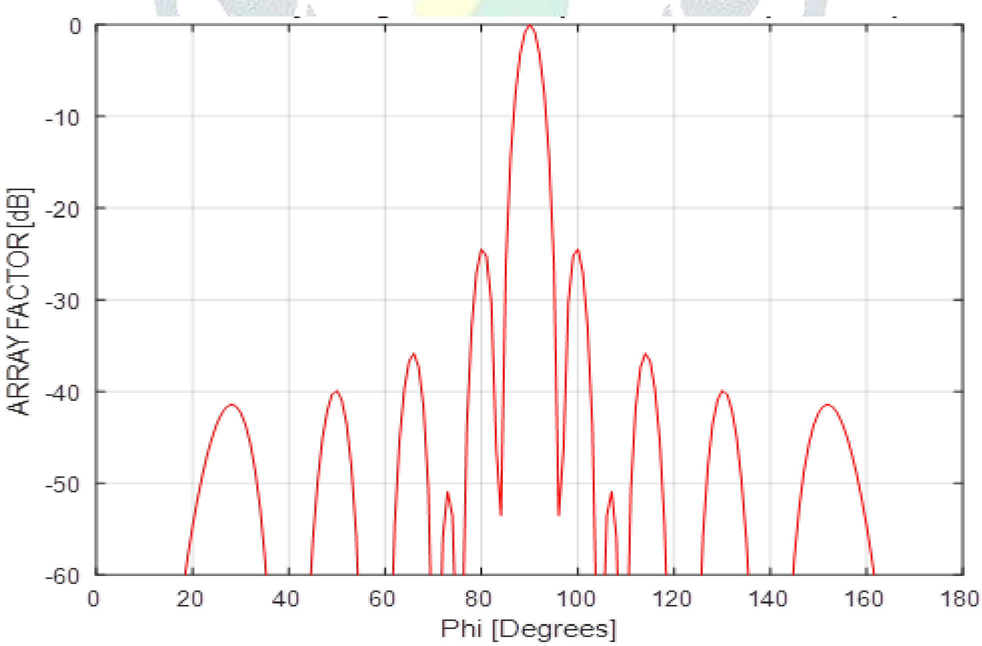

Fig7. LDAA using PSOGSA amplitude optimization

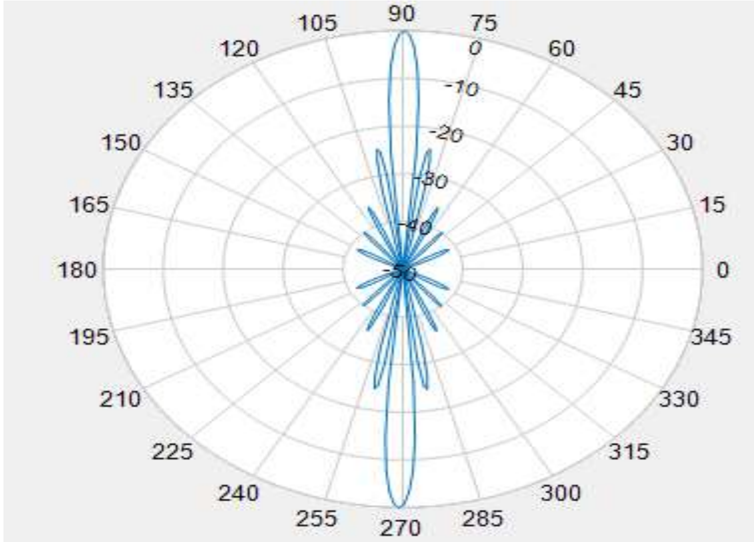

Fig8. .Normalized E-plane pattern for optimized 18 element LDAA

5. Conclusion

Recent progress on high gain array antennas is setting the stage for the next generation of cellular evolution. High gain, low sidelobe level array antennas are the most promising class of antennas to better perform in the future dense and high data rate communication environment. PSO and GSA is a new technique in electromagnetics optimization. It was applied on the optimization of linear dipole antenna arrays. In this design, the PSOGSA is successfully applied to determine the optimized parameters of LDAA. This algorithm efficiently provides the design of an optimum LDAA to generate the radiation pattern with desired properties. The effectiveness of this algorithm will be more impressive when it will be applied to some more complicated antenna array with more number of design and performance parameters.

References

[1] J. Capon, "High-resolution frequency-wavenumber spectrum analysis," *Proceedings of the IEEE,* vol. 57, pp. 1408-1418, 1969.

[2] H. L. Van Trees, *Optimum array processing: part IV of detection, estimation, and modulation theory*, 1st ed. New York: Wiley, 2002.

[3] C. Pan, J. Chen, and J. Benesty, "Performance study of the MVDR beamformer as a function of the source incidence angle," *IEEE/ACM Transactions on Audio, Speech, and Language Processing,* vol. 22, pp. 67-79, 2014.

[4] S. Darzi, S. K. Tiong, M. T. Islam, M. Ismail, and S. Kibria, "Optimal null steering of minimum variance distortionless response adaptive beamforming using particle swarm optimization and gravitational search algorithm," in *IEEE 2nd International Symposium on Telecommunication Technologies (ISTT)*, 2014, pp. 230-235.

[5] Y. L. Chen and J.-H. Lee, "Finite data performance analysis of LCMV antenna array beamformers with and without signal blocking," *Progress In Electromagnetics Research,* vol. 130, pp. 281-317, 2012.

[6] O. Besson and F. E. Vincent, "Performance analysis of beamformers using generalized loading of the covariance matrix in the presence of random steering vector errors," *Signal Processing, IEEE Transactions on*, vol. 53, pp. 452-459, 2005.

[7] S. Salem, T. S. Kiong, J. K. S. Paw, and G. C. Hock, "Artificial immune system assisted Minimum Variance Distortionless Response beamforming technique for adaptive antenna system," in *International Conference on ICT Convergence (ICTC'13)*, 2013, pp. 938-943.

[8] D. D. Feldman and L. J. Griffiths, "A projection approach for robust adaptive beamforming," *Signal Processing, IEEE Transactions on*, vol. 42, pp. 867-876, 1994.

[9] Z. D. Zaharis and T. V. Yioultsis, "A novel adaptive beamforming technique applied on linear antenna arrays using adaptive mutated boolean PSO," *Progress In Electromagnetics Research,* vol. 117, pp. 165-179, 2011.

[10] F. Liu, J. Wang, C. Sun, and R. Du, "Robust MVDR beamformer for nulling level control via multi-parametric quadratic programming," *Progress In Electromagnetics Research C,* vol. 20, pp. 239-254, 2011.

[11] C.A. Balanis, Antenna theory: analysis and design,3rd edition,Singapore: John Wiley &Sons,Inc.,2005.

[12] Saumendra K. Mohanty, Guru P. Mishra, and B. B.Mangaraj, "Implementing Taguchi and Cuckoo Search toOptimize LAA"India Conference (INDICON), 11-13 December 2014 Annual IEEE, pp.1-5, Pune, Maharashtra, India.

[13] A. M. Mohdmed,K.R.Mahmoud, S.G.Abdel Gawad, and I.I.Ibrahim, "Direction of arrival estimation based on maximum likely hood criteria using GSA,"PIERS Proceedings,1162 1167,Taipei,Mar.25-28,2013.

[14] K. R. Mahmoud, "UWB antenna design using gravitational search algorithm,"Journal of engineering sciences,Vol.41,No. 5,faculty of engineering, Assiut University,Sept.2013.

[15] S. Mirjalili and S. Z. M. Hashim, "A new hybrid PSOGSA algorithm for function optimization," in *international conference on Computer and Information Application (ICCIA'10)*, 2010, pp. 374-377.