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Synthesis of Linear Antenna Array Using Modified Teaching-Learning-Based Optimization

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ABSTRACT
In wireless, radar, long distance applications low side lobes with narrow beams is needed. But there exists a trade-off between side lobe level (SLL) and beam width in radiation pattern of antenna array. In order to overcome this optimization algorithm is used for reduction of SLL in antenna array. In this paper, MTLBO optimization method is used to optimize the linear antenna array. In MTLBO algorithm, the basic TLBO algorithm is modified using Differential Evolution with Random-Scale Factor (DERSF). The results of MTLBO are compared with GA, MDE optimization algorithms. MTLBO shows better results compared to other techniques in yielding lowest SLL with appreciable beamwidth.

***Keywords* -** Antenna array, Beamwidth, Optimization Algorithm, Sidelobe Level.

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I. INTRODUCTION

Antenna arrays play a crucial role in used in wireless communication, radar, military, long distance applications etc. The set of same type of antennas worked as a whole is called antenna array. The antenna array provides adjustable radiation pattern compared to single antenna. The advantage of antenna arrays is that just by modifying the inputs given to the array (like current amplitudes, phases and distance between the antennas in array), the radiation pattern with desired shape can be attained. The side lobes can be reduced, nulls can be adjusted in the desired direction; different shapes of the radiation pattern can be adjusted using antenna array. The optimization of SLL is a serious problem in antenna arrays. The trade-off between SLL and beamwidth is reduced using optimization algorithms.

TLBO is a new approach without any need of algorithm specific parameters; it needs only common controlling parameters like population size and maximum number of iterations to function. The aim of this paper is to optimize the sidelobe level of LAA using MTLBO and compare the results with other random stochastic techniques. The current excitations of the antenna array are modified to reduce the SLL. The optimization of SLL is done and results are compared with GA, MDE. MTLBO provides good results and better convergence rate compared to GA, MDE.

II. ANTENNA ARRAY

2.1. Linear Antenna array (LAA):

The group of antenna elements arranged in linear fashion is called a linear antenna array. The array factor is sum of radiation patterns of all the antennas in the antenna array.

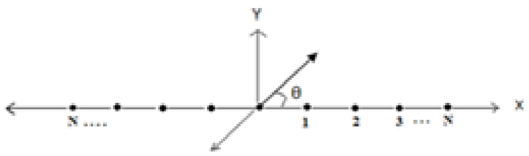

Fig.1. Symmetrical Linear antenna array

For even number of antenna elements (2N) the array factor is given by

$$\boldsymbol{AF = \sum_{n=-N}^{-1} I_n\, e^{j(n+0.5)\Phi} + \sum_{n=1}^{N} I_n\, e^{j(n-0.5)\Phi}} \quad (1)$$

For odd number of antenna elements (2N+1) the array factor is given by

$$\boldsymbol{AF = \sum_{n=-N}^{N} I_n\, e^{jn\Phi}, (I_0 = 1)} \quad (2)$$

AF = Array factor, I_n = Current amplitude at n^{th} element, Total phase of antenna array, $\Phi = \beta d\cos\theta + \alpha$, Phase constant, $\beta = 2\Pi/\lambda$, $\lambda = 1$, d = distance between the antenna elements, θ = Observation angle, α = Phase of antenna element.

III. OPTIMIZATION ALGORITHM

3.1. Genetic Algorithm (GA):

GA is evolutionary based optimization algorithm inspired from Darwin's theory of evolution. Only the fittest solutions are selected for generation with a hope that new generation is better than old generation (parents). The population is initialized. The solutions are selected based on fitness function. Then solutions are updated using two main operators: 1. Crossover, 2. Mutation iteratively until the optimal solution is obtained. In crossover operation the offspring will have the characteristics of the parents. The mutation operation maintains diversity and stop premature local optimum convergence.

3.2. Modified Differential Evolution (MDE):

The basic DE has mainly two disadvantages: low convergence rate and low exploration capabilities. These disadvantages are overcome in MDE by using DE/rand-to-best/2 mutation process. The population is initialized. The solutions are updated iteratively using mutation process. The crossover operation is used for selection between initial solution vectors and mutated vectors creating trail vectors. Finally, the selection between trail and parent vectors is done based on fitness values. This process is continued until the termination criterion is met.

3.3. Modified TLBO:

TLBO belongs to algorithm specific parameter less algorithms. It is inspired from teaching and learning process in class. The mechanism how students acquire knowledge from teacher and through interaction with other students is the main motivation of the algorithm. There are two stages in this algorithm:

1. Teacher stage
2. Learner stage.

In teacher stage, learners acquire knowledge from teacher. The best solution among the population is considered as teacher solution. The overall learning average of the outcomes is improved in class in teacher stage.

$$S_{new} = S_{old} + r_1 \, (S_{best} - T_f \, S_{mean}) \qquad (3)$$

S_{new} is the updated solution in teacher's stage. S_{old} is the learner solution that is to be updated. r_1 is a randomly distributed vector in the range (0, 1). S_{best} is teacher solution. S_{mean} is mean of all the learner solutions. T_f is teaching factor. T_f will be either 1 or 2.

$$T_f = \text{round}\,[1 + (\text{rand}\,(0, 1) * (2-1))] \qquad (4)$$

In learner stage, the students improve his/her skills from other students who have better skills than him/her. Randomly select two learners S_a, S_b.

If S_a has more knowledge than S_b,

$$S_{new} = S_{old} + r_2 \, (S_a - S_b) \qquad (5)$$

Else

$$S_{new} = S_{old} + r_2 \, (S_b - S_a) \qquad (6)$$

S_{new} is the updated solution in learner's stage. r_2 is randomly distributed vector in the range (0, 1). The new learner (S_{new}) is updated only when S_{new} has more knowledge than S_{old}.

A learner always tries to improve his/her knowledge with the help of teacher or with interaction of other learners. Considering this phenomenon, the random vector in learner's stage r2 is replaced with R in modified TLBO. This is inspired from approach of Differential Evolution of Random-Scale Factor (DERSF). R is a randomly distributed vector in the range (0.5, 1).

$$R = 0.5(1 + \text{rand}\,(0, 1)) \qquad (7)$$

The searching capabilities of the algorithm are improved in MTLBO compared to TLBO. It also shows better convergence rate and efficiency. MTLBO depends only on common algorithm parameters like population size, size of design variables and number of iterations. The population with 'N' learners is initialized. The learner solutions are updated by both teacher and learner stages. The new solutions are updated in population only when the objective function values of new learner solutions are better than old learner solutions.

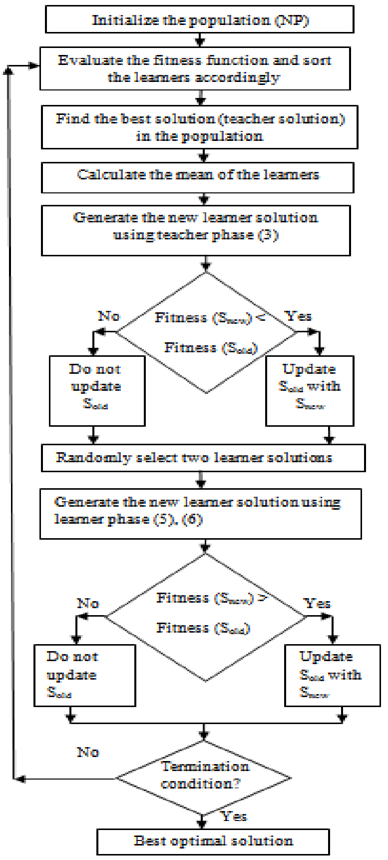

Fig.2. Flowchart of MTLBO

IV. RESULTS

The side lobe level of LAA is optimized using GA, MDE and MTLBO. The maximum number of iterations is considered as termination criteria. LAA is optimized for both even and odd antenna elements using (1), (2). MATLAB 2009b is used for simulation. The fitness function used to reduce SLL is,

Fitness = max (20log |AF (θ) / AF_{max}|);

θ = $[0,90^0]$

Maximum number of iterations = 100

Number of solutions, N = 100

Length of learner, P = length of antenna array.

The phase between the antenna elements is kept constant, $\alpha = 0^0$.The spacing between the elements is kept constant, d = 0.5λ.

Parameters of GA:

Crossover probability = 0.85

Mutation probability = 0.01

Parameters of MDE:

Maximum and minimum scale factor, SF_{max}=1; SF_{min}=0.9

Maximum and minimum scale factor,

CP_{max}=0.9; CP_{min}=0

The scale factor and cross probability is updated iteratively using

$$SF(i) = \frac{\ln\left(\frac{SF_{min}}{SF_{max}}\right)}{maxite}$$

$$CR(i) = CR_{min} + (CR_{max} - CR_{min}) * \left(\frac{i}{maxite}\right)$$

MTLBO does not require any algorithm specific parameters. It works only on common algorithm parameters. MTLBO provides better results compared to other algorithms in providing lowest sidelobe level with appreciable beamwidth (Tables: 1-3). The results for 16, 19 and 24 elements of LAA are shown in Fig. 2-4.

Table-1. Current excitations and SLL of 16-element LAA

Algorithm	Current Amplitudes	SLL (dB)
GA	1.0000,0.9747,0.8441, 0.8264,0.5275,0.4717, 0.3676,0.2175	-27.66
MDE	1.0000,0.9514,0.8681, 0.7102,0.5979,0.4188, 0.3119,0.2272	-31.24
MTLBO	1.0000,0.9491,0.8534, 0.7245,0.5769,0.4263, 0.2869,0.2362	-32.10

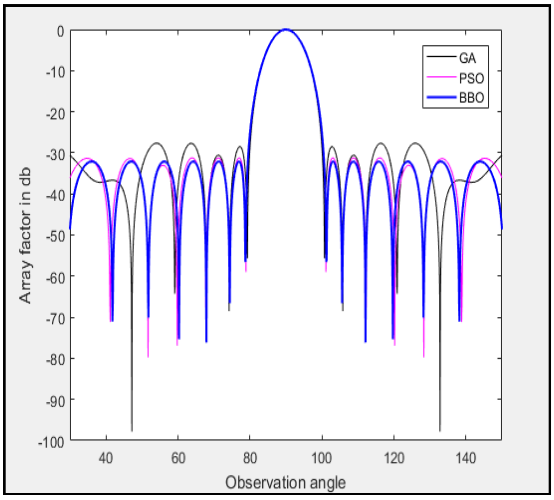

Fig.3. Radiation pattern of 16-element LAA

Table-2. Current excitations and SLL of 19-element LAA

Algorithm	Current Amplitudes	SLL (dB)
GA	0.9583,0.9526,0.8172 0.7725,0.5808,0.5012 0.2933,0.3119,0.1642	-31.12
MDE	0.9511,0.9290,0.8222, 0.6865,0.5830,0.4485, 0.3317,0.2248,0.1412	-33.55
MTLBO	1.0000,0.9195,0.8518, 0.7122,0.6061,0.4503, 0.3462,0.2154,0.1936	-35.22

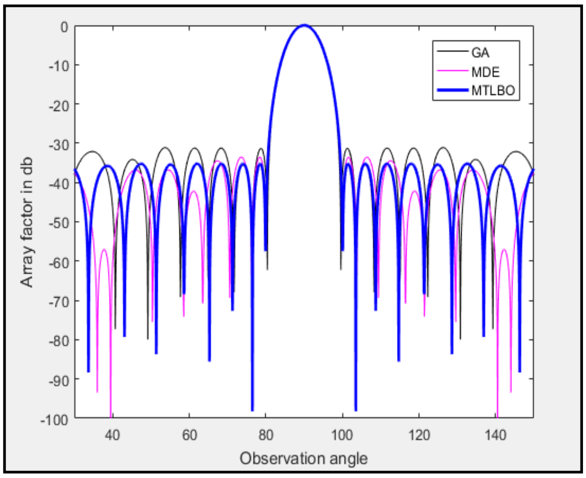

Fig.4. Radiation pattern of 19-element LAA

Table - 3. Current excitations and SLL of 24-element LAA

Algorithm	Current Amplitudes	SLL (dB)
GA	1.0000,0.9881,0.9679, 0.9494,0.6870,0.3064, 0.4651,0.5875,0.2059, 0.4267, 0.1184,0.1740	-22.36
MDE	1.0000,0.9334,0.9169, 0.8526,0.7494,0.6275, 0.5280,0.4477,0.3077, 0.2731, 0.1400,0.1073	-34.71
MTLBO	1.0000,0.9622,0.9128, 0.8374,0.7306,0.6267, 0.5231,0.4025,0.2995, 0.2228, 0.1395,0.1104	-40.49

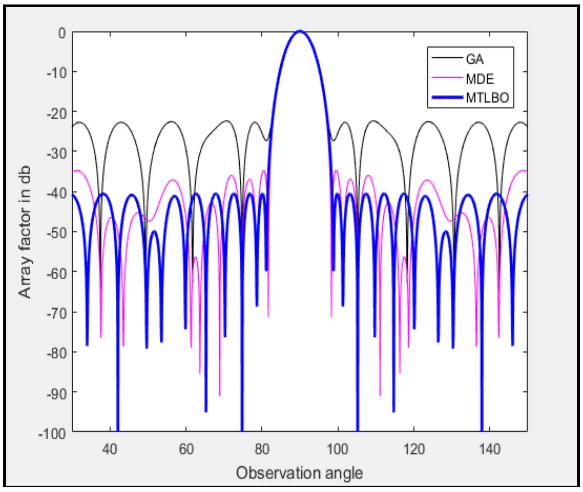

Fig.5. Radiation pattern of 24-element LAA

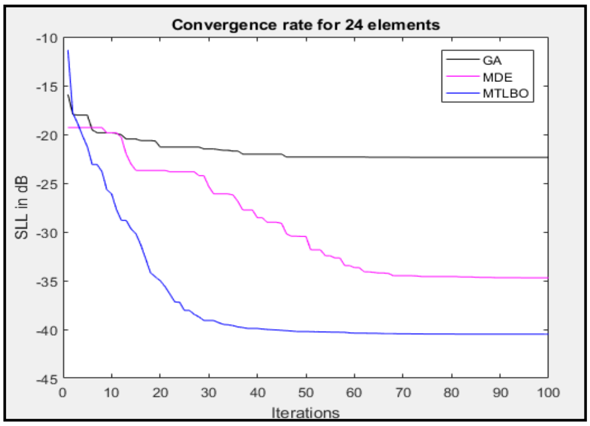

Fig.6. Convergence plots for GA, MDE and MTLBO of 24-element LAA

V. CONCLUSIONS AND FUTURE SCOPE

In this paper, optimization of SLL of LAA is done for 16, 19 and 24 element antenna array using MTLBO, MDE and GA. MTLBO provides best SLL of -37.53dB for 16 elements, -35.22 dB for 19 elements and -40.49dB for 24 elements. MTLBO gives better results compared to GA, MDE. The results show that MTLBO provides lowest sidelobe level with appreciable beamwidth. The convergence plot indicates that MTLBO converges faster to best optimal solution when compared with GA, MDE. MTLBO is algorithm specific parameter less algorithm. The controlling and tuning of parameters which is difficult and time consuming process does not belong to MTLBO. It is easy to implement and powerful. For further extension of this paper, SLL reduction can also be done by modifying phase excitations of antennas in array or spacing between the antennas.

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