

Linear Antenna Array Synthesis using a Hybrid Method of Moments and Genetic Algorithm to Reduce the Side Lobe Level

K.Yedukondalu¹, T.Venkateswarlu², M.Durga Rao³

PG scholar, Dept. of ECE (Communication Systems), SVUCE, SV University, Tirupati, India ¹

Professor, Dept. of ECE, SVUCE, SV University, Tirupati, India ²

Scientist/Engineer-SE, RADG, National Atmospheric Research Laboratory (NARL), Gadanki, India ³

Abstract - Side lobe level (SLL) reduction has a significant importance in atmospheric radar systems. It reduces the effect of unwanted signals outside the main lobe. Many attempts based on analytical schemes are exerted for this purpose. However, these methods are developed for specific problems like synthesis of restricted radiation patterns only. Optimization algorithms are utilized for more general problems. In this paper, the synthesis technique is implemented based on the combination of method of moments (MoM) and genetic algorithm (GA). This hybrid synthesis technique is giving the better results than that of Genetic algorithm and Taylor's analytical method. This method takes the number of elements and element spacing as input and gives element coefficients as output for synthesizing the desired radiation pattern. This entire process is performed based on the condition that half power beam width (HPBW) is equal to that of uniform linear array pattern.

Key Words: Method of Moments (MoM), Genetic Algorithm (GA), Side Lobe Level(SLL), Linear Antenna Array.

I. INTRODUCTION

Many research efforts are attempted to reduce the SLL of the linear antenna array by introducing the non-uniform element spacing between the antenna array elements with the help of evolutionary algorithms such as Genetic algorithm[1], Differential evolutionary algorithm[5], particle swarm optimisation[6], etc. Unfortunately, these algorithms are limited for little number of antenna elements and these iterative methods suffer some drawbacks as, a small reduction in the side lobes affects much broadening in the half power beam width. Side lobe Level reduction technique was proposed for optimisation using only Genetic Algorithm in [1]. But with the help of only genetic algorithm the side lobes are reduced chaotically. In

this way, this proposed method gives better results where the side lobes are reduced exponentially and linearly with the main lobe.

In this method, it takes the number of elements and element spacing as input and gives the element coefficients as output for synthesizing the desired radiation pattern. This entire process is performed based on the condition that half power beam width (HPBW) is equal to that of uniform linear array pattern.

II. AN OVERVIEW OF GENETIC ALGORITHM

In 1960s, John Holland was first introduced a simple example on the Genetic Algorithm which is a class of Evolutionary algorithms. This optimisation algorithm is more powerful for problems with more number of variables. It optimises the efficient solution in its large and complex solution space.

The performing criterion flow chart of the genetic algorithm is shown in the fig.1.

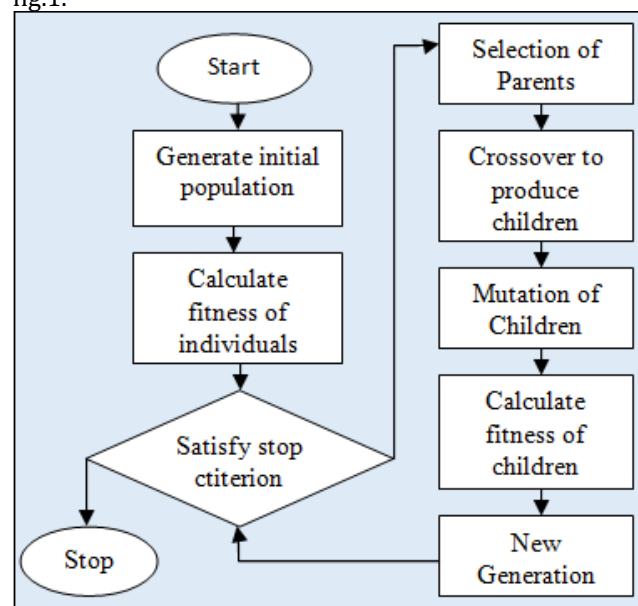


Fig.1: GA reproduction flow chart.

The basic important Parameters of GA can be

- Initial Population
- Selection
- Crossover
- Mutation
- Number of Generations
- Stopping criteria.

Initial Population: The number of chromosomes considered initially. Here the population size is 10.

Selection: The selection of which individuals from the initial population will go on to reproduce new generation. In this method Roulette wheel Selection is used.

Crossover: This is an exchange of substrings denoting chromosomes for an optimisation. In this method single point crossover is used.

Mutation: The modification of single bit strings in a single individual. It plays a big role in GA.

Here the mute rate is 0.3.

Number of generations: The maximum number of generations that the GA can evolve before it terminates.

Stopping Criteria: The terminating condition of evaluation of fitness function (cost function) for getting optimised output. It may be when

- A solution that satisfies the minimum value of cost function.
- A maximum number of generations reached.
- A maximum number of Function callings reached.

III. AN OVER VIEW OF METHOD OF MOMENTS

The method of moments is a family of numerical methods and is based on solving of system of linear equations of the matrix form as shown below.

$$[Z]_{N \times N} [I]_{N \times 1} = [V]_{N \times 1} \quad (1)$$

Where $[I]_{N \times 1} = [w_1 \ w_2 \ w_3 \ \dots \ w_N]^T$ is the excitation coefficients to be determined by using linear equations given by the above matrix form.

- The first step in the MoM is to assign a basis function that discretizes an integral equation to form a polynomial with unknown coefficients.
- The second step is to introducing a testing procedure to generate system of linear equations that could be solved for the unknown coefficients according to (1).

IV. PROBLEM FORMULATION

The array factor for a linear antenna array consisting of N isotropic elements antenna elements positioned symmetrically along the z -axis with uniform element spacing d is given by:

$$AF(\theta) = \sum_{n=1}^N w_n e^{j\left(n - \frac{N+1}{2}\right)kd \cos \theta} \quad (2)$$

Where w_n is the excitation coefficient of the n^{th} element, d is the spacing between array elements, $k=2\pi/\lambda$ is the receiving wave number, θ is the angle between the array broadside to the receiving signal. The SLL reduction for optimised element spacing using MoM/GA was found in [8]. Whereas this method is to implement for fixed length of element spacing as 0.56λ . As mentioned in the second step of the MoM, The array factor takes the form as follows

$$\langle AF_s(\theta), f_m \rangle = \langle AF_d(\theta), f_m \rangle \quad (3)$$

Where $AF_s(\theta)$ is synthesised array factor and $AF_d(\theta)$ is desired array factor. Where inner product in (3) is defined as

$$\langle x, y \rangle = \int_0^\pi xy \, d\theta \quad (4)$$

In this method, It is not required to take the first step of MoM because uniform array factor itself contains a polynomial. Based on the formulation (2) the appropriate choice for the basis polynomial for finding coefficients of the weighting function is

$$f_m = \int_0^\pi e^{-jkd \cos \theta} \quad (5)$$

$$m=1,2,3,\dots,N$$

After that, the elements of the $[Z]_{N \times N}$ matrix can take the form as follows

$$Z_{mn} = \int_0^\pi e^{j(n-m)kd \cos \theta} \quad (6)$$

$$m=1,2,3,\dots,N$$

$$n=1,2,3,\dots,N$$

for finding coefficients of matrix $[I]_{N \times N}$ it is required to find the elements of the matrix $[V]_{N \times 1}$.

For finding desired array factor the procedure will start by generating the original array pattern by using (2), then it will be multiplied with the rectangular function whose beamwidth is equal to the bottom beamwidth of the original array pattern. Then the shaped array pattern will take the form as shown below

$$AF_{shaped}(\theta) = AF_{uniform}(\theta) \times f_{rect}(\theta) \quad (7)$$

The resulting shaped pattern in (7) will raise to a certain level hallowing the smooth extension of the pattern slightly above the zero level. Then the raised pattern will be given by

$$AF_{raised-sh}(\theta) = AF_{shaped}(\theta) + h \times f_{rect}(\theta) \quad (8)$$

Where h is the amplitude of the rectangular function for raising the level of the shaped pattern in (7). Then the raised pattern in (8) will be raised to an exponent n in order to keep the desired beamwidth that is changed slightly by raising the pattern by the level h .

In this case the elements of the vector $[V]_{N \times 1}$ is given by

$$V_m = \int_0^\pi (AF_{raised-sh}(\theta))^n e^{-j(m - \frac{N+1}{2})kd \cos \theta} \quad (9)$$

Upto now the formulation method for MoM is completed. Then it is required to compute the optimum values for parameters h and k by using GA for achieving the minimum side lobe level. Here, the cost function (CF) is to be minimised is given by

$$CF = 1 - \frac{|SLL_o - SLL_s|}{|SLL_o|} + |HPBW_s - HPBW_o| \quad (10)$$

Where SLL_o, SLL_s are the side lobe levels of the original uniform array pattern and the synthesised array pattern. $HPBW_s, HPBW_o$ are the half power beamwidths of the synthesised and original array patterns.

GA optimisation process is performed within the ranges $1 \leq n \leq 2$ and $5 \leq h \leq 15$.

V. RESULTS AND DISCUSSIONS

Consider a 24 element antenna array pattern for linear array using equation (2). It's SLL, HPBW and bottom beamwidth of the main lobe are measured as -13.2dB, 4.14° and 13° respectively. By using the same number of antenna elements the SLL reduction is performed by adjusting the h and n values using the genetic algorithm.

A. Results for fixed element spacing as 0.56λ .

GA, within 35 iterations, is given the parameter values of h, n , as 15, 1.1 respectively for 20 elements arranged symmetrically about z-axis. The resultant SLL for these values is -30.84 dB. The weighting coefficients of this pattern are shown in column4 in table 1. The array pattern for these weights is shown in Fig.2. The existed method [1] for 20 elements has taken 51 iterations and was given the SLL as -18.7dB which is greater than almost 12.14dB with our proposed method.

GA, within 32 iterations, is given the parameter values of h, n , as 12, 1.1 respectively for 24 elements arranged symmetrically about z-axis. The resultant SLL for these values is -43.84 dB. The weighting coefficients of this pattern are shown in column3 in table 1. The array pattern for these weights is shown in Fig.3. The existed method [1] for 24 elements has taken 57 iterations and was given the SLL as -14.97dB which is greater than almost 28.87dB with our proposed method.

B. Results for fixed element spacing as adjusted by GA.

GA in 47 iterations has given the parameter values of h, n , and d as 8, 1.31, 0.893λ respectively for 20 elements arranged symmetrically about z-axis. The resultant SLL for

these values is -43.84 dB. The weighting coefficients of this pattern are shown in column 5 in table 1. The array pattern plot for these weights is shown in Fig.3. The advantage with uniform spacing fixed by the GA will give all side lobes approximately equal and below -40dB.

GA in 45 iterations has given the parameter values of h, n and d as 8, 1.4, 0.882λ for 24 elements arranged symmetrically about z-axis. The resultant SLL for these values is -43 dB. The weighting coefficients of this pattern are shown in column6 in table 2. The array pattern plot for these weights is shown in Fig.5. This method gives the results better than Taylor's distribution.

Weight Number	Uniform	Synthesized Array pattern weights using MoM/GA			
	N=24 d=0.56λ	N=24 d=0.56λ	N=20 d=0.56λ	N=20 d=0.893λ	N=24 d=0.882λ
W ₁	1	0.18895	0.3078	0.026519	0.0924
W ₂	1	0.38009	0.6776	0.037878	0.2821
W ₃	1	0.59379	1.0547	0.073284	0.6361
W ₄	1	0.92286	1.5065	0.13131	1.2052
W ₅	1	1.303	1.9678	0.20855	2.0224
W ₆	1	1.7382	2.4158	0.29816	3.0859
W ₇	1	2.2018	2.8326	0.39027	4.3511
W ₈	1	2.6449	3.1629	0.4734	5.7289
W ₉	1	3.0652	3.4100	0.53637	7.0920
W ₁₀	1	3.3965	3.5316	0.57031	8.2936
W ₁₁	1	3.6463			9.1911
W ₁₂	1	3.769			9.6711

Table1. Weighting coefficients of arrays for 24 and 20 elements with element spacing as $0.56\lambda, 0.896\lambda$ and 0.886λ .

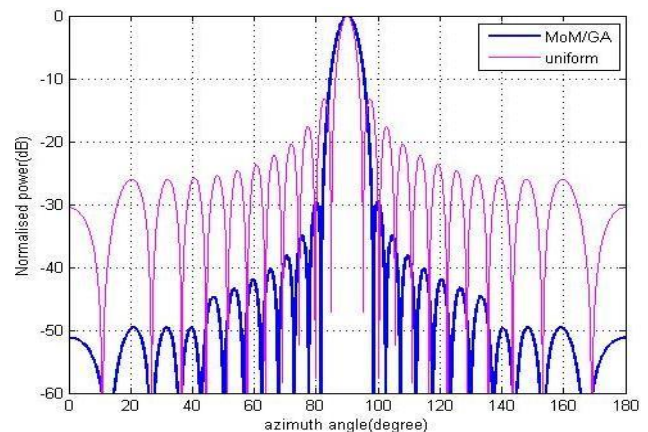


Fig.2. Radiation pattern for $h=15, n=1.1, N=20, d=0.56\lambda$ and weighting coefficients given in column 3 of Table 1.

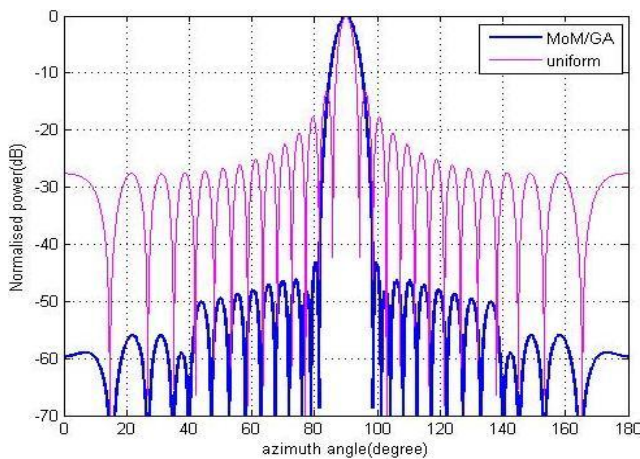


Fig.3. Radiation pattern for $h=12, n=1.1, N=24, d=0.56\lambda$ and weighting coefficients given in column 2 of Table 1.

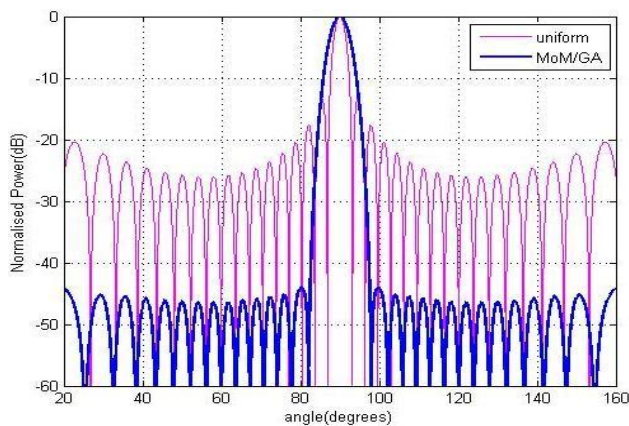


Fig.4. Radiation pattern for $h=8, n=1.31, N=20, d=0.893\lambda$ and weighting coefficients given in column 4 of Table 1.

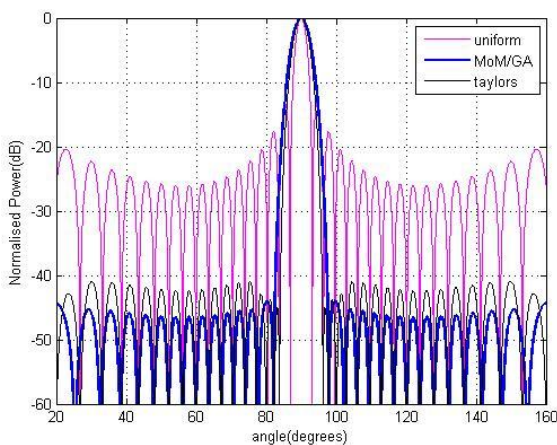


Fig.5. Radiation pattern for $h=8, n=1.4, N=24, d=0.882\lambda$ and weighting coefficients given in column 5 of Table 1.

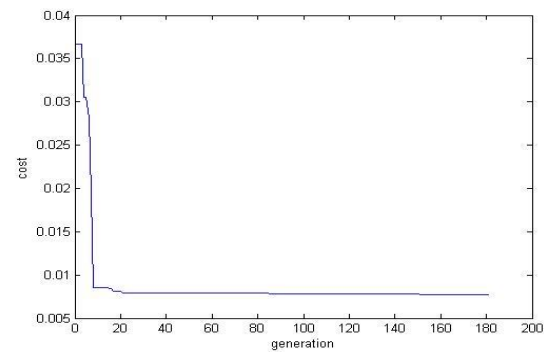


Fig.6. Convergence of cost function for side lobe level reduction with respect to generations for $N=20, d=0.56\lambda$

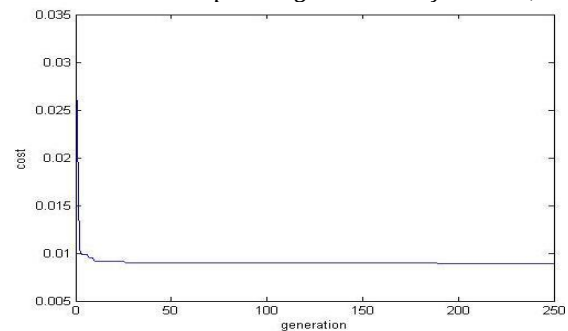


Fig.7. Convergence of cost function for side lobe level reduction with respect to generations for $N=24, d=0.56\lambda$.

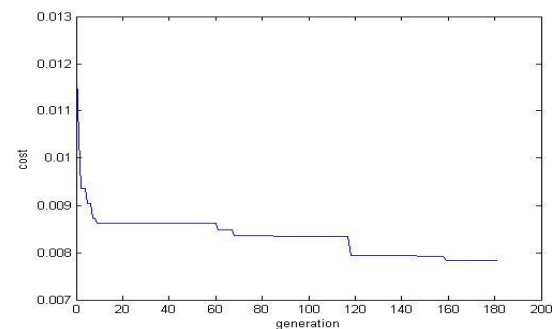


Fig.8. Convergence of cost function for side lobe level reduction with respect to generations for $N=20, d=0.893\lambda$.

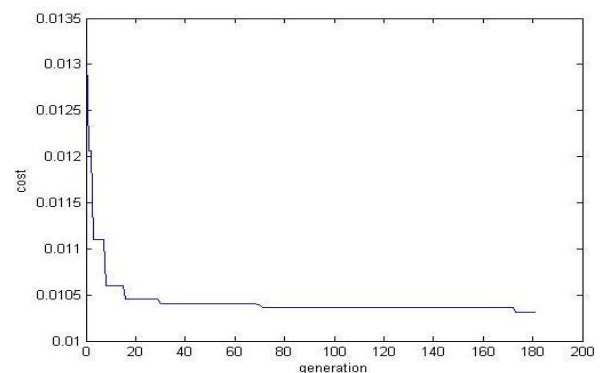


Fig.9. Convergence of cost function for side lobe level reduction with respect to generations for $N=24, d=0.882\lambda$.

IV. CONCLUSION

In this paper, the method is based on the combination of Method of moments and Genetic algorithm for reducing the side lobe level of linear antenna array. It is observed for both uniform element spacing optimized by Genetic Algorithm and uniform element spacing as 0.56λ which is fixed for HF radar in National Atmospheric Research Laboratory, Gadanki in India. This method is giving the better results in reducing the side lobe levels than that of Genetic Algorithm and Taylor's distribution.

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BIOGRAPHY



K.Yedukondalu has received the B.Tech degree in E.C.E from S.K University, Anantapur, India in 2012. He joined as M.Tech Scholar in the department of ECE in SV University, Tirupati, India in 2013. His research and teaching areas of interest in Communication Systems and Signal

Processing.



T.Venkateswarlu has received the B.Tech and M.Tech degrees in E.C.E from S.V University, Tirupathi, India in 1979 and 1981 respectively. He received Ph.D from IIT Madras in 1990. After working a short period at KSRM college of engineering Kadapa. He joined the faculty of the department of EEE, SVU. He is currently with faculty of ECE, SVU as a professor and chairman board of service. During the period from July 1997 to 2000, he worked as faculty member at Multimedia University, Melaka, Malaysia. His teaching interest in the area of ECE and Signal Processing.



M.Durga Rao, born in 1980, received B.E. degree in E.C.E at Sir.C.R.R. College of Engineering, Eluru in 2002 and M.Tech in Electronic System design and Communication Engineering at NIT, Rourkela, in 2005. He worked as Scientist/Engineer at Vikram Sarabhai Space Centre, Trivandrum, during the period 2004-2010. He is currently working as scientist/Engineer-SE in the group of RADG in National Atmospheric Research Laboratory, Gadanki in India from December 2010. His areas of interest include development of active phased array radars.