SSRG International Journal of Electrical and Electronics Engineering
ISSN: 2348-8379/ https://doi.org/10.14445/23488379/IJEEE-V10I3P110

Volume 10 Issue 3, 94-103, March 2023

Original Article

Synthesis of Difference Patterns using Genetic Algorithm

K. Ramya[1], G S N Raju[2], PA Sunny Dayal[3]

[1,2,3]*Electronics and Communication Engineering, Centurion University of Technology and Management, INDIA*

[1]*Corresponding Author : kramya@cutmap.ac.in*

Received: 21 January 2023 Revised: 06 March 2023 Accepted: 18 March 2023 Published: 29 March 2023

Abstract *- Pattern synthesis is one of the most important problems in all wireless communications and Radar systems. Each application demands the generation of a different type of radiation pattern structure. Pencil beams are generated either from parabolic dish antennas or from array antennas for point-to-point communication. Similarly, sector beams are used in search Radars. On the other hand, csc^2 beams are used for ground mapping and airport surveillance. However, the difference patterns associated with narrow beams are sequentially used in IFF radars. In the present work, investigations are carried out to optimize such difference patterns from array antennas. The patterns are designed using a genetic algorithm, and the results are compared with those of Taylor's distribution. The patterns are presented in $\sin\theta$ Domain for different arrays. It is found from the results; the designed patterns are extremely useful in all search applications.*

Keywords *– Array, Genetic Algorithm, Radiation pattern, Side Lobe Level, SLS difference pattern, Sum pattern.*

1. Introduction

In all communications and Radar systems, the antenna is an essential device to perform desired functions [1]. Antenna types are large in number, and they vary in size, which is inversely proportional to the frequency of operation [1]. That means the higher the frequency, the smaller the size of the antenna, and vice-versa. The smallest size of the antenna is a Hertzian dipole, whose length is much smaller than $'\lambda'$. However, it is only a theoretical element and cannot be excited practically. Quarter-wave monopoles and half-wave dipoles are generally used in combination with other elements. This is due to impedance matching requirements. Monopoles are popular in automobiles, and dipoles are widely used in yagi-uda arrays and log-periodic arrays. It may be pointed out that the yagi-uda array is a narrowband antenna. The log-periodic array is frequency independent, and hence it can be used for TV reception to receive a greater number of channels. The antennas mentioned above can be fabricated in the form of printed antennas to save space.

Individual elements are constrained by limited gain, and fixed directivity and impedance problems often arise. These problems and constraints can be suitably addressed by using those elements in the form of arrays [1-3]. The array elements can be linear or nonlinear. They can also as well be planar type. The planar arrays are preferred in applications where the scanning is required either in elevation in azimuth or both [4]. It is possible to control the gain, directivity, radiation characteristics, and beam shapes using array antennas.

Over and above, pattern synthesis is one of the most important problems to be solved by antenna designers [5-6]. It is the process to make the desired pattern in the required shape with minimum side lobe level. The pattern consists of the main lobe, which is the radiation in the required direction, and the side lobes are to represent the radiation in an unwanted direction. More side lobe level reduces the original signal power [S], so reducing side lobe level is the most important factor in pattern synthesis. Pattern synthesis is achieved by adjusting array excitations such as amplitude, phase, or both amplitude and phase or by adjusting element positions of an array with uniform or non-uniform spacing [7-8]. Each user demands a specific pattern shape depending on the application under consideration. Each shape of the radiation beam has its application in both radar and wireless communications [9]. In fact, the arrays are also used in electromagnetic radiation therapy applications.

For example, Pencil beams are very sharp, highly focused narrow beams used for point-to-point communications and in high angular resolution radar in search applications [9]. It is not easy to meet the objectives if a narrow beam is scanned to detect fast-moving objects. As the beam is very narrow, it requires many scans. This leads to generating broad beams or sector beams to reduce the number of scans in searching. This, again, is constrained by the small ripples in the trade in regions. Csc^2 beams are essentially generated for ground mapping and airport surveillance radar [10].

Several researchers in the open literature present multiple pattern synthesis methods. In standard distribution methods, the SLL is reduced from one distribution to another at the cost of increasing the main beam width. The empirical methods are the experimental methods implemented based on the measured pattern data under realistic conditions [11]. It is a very laborious and time-consuming method, requiring measured data until the optimum design is achieved. The conventional analytical pattern synthesis methods are developed to improve specific pattern characteristics; dealing with one parameter improvement may degrade the other parameters [12]. These analytical synthesis methods have limitations and cannot control multiple parameters. Evolutionary/stochastic/meta-heuristic algorithms can handle a greater number of optimization parameters to control [12]. Among these, the Genetic algorithm (GA) is one of the best optimization techniques, and it is useful to solve problems in every domain. It takes care of constrained and unconstrained parameters. This algorithm is evolved based on natural selection. It modifies the population of individual solutions. An individual is characterized by a set of variables, which are known as genes. A chromosome is usually called a solution which is formed by joining the genes into a string.

In general, a set of genes of an individual is represented using a string in terms of alphabets. However, a string of 1's and 0's is used in terms of binary values. The genetic algorithms are classified into the following types, namely generational GA, steady state general algorithm, and steady generational genetic algorithm. The main components in the GA operation are crossover, mutation, and selection of the fittest. The GA is used in all problems, either in computer science or in operations research. The GA is a metaheuristic, and the process of natural selection inspires it. It belongs to a larger class of evolutionary algorithms.

2. Genetic Algorithm

This paper uses a genetic algorithm to determine the amplitude weights for achieving low SLL (Sidelobe level). It is a nature-inspired kind of global evolutionary search optimization algorithm [13] that works on selecting the best chromosomes from the parent population via crossover and mutation operators according to the fitness function value to generate the new population in a better way. The fitness function selects the individual chromosomes from the parents or present generations [13]. The algorithm continues until it meets the optimized solution or until the maximum generations limit is crossed [35]. Figure 1 shows the details of GA in the form flowchart.

The Genetic Algorithm contains the following parameters

2.1. Chromosome

The chroma means colored, and soma means body. Therefore chromosomes mean colored bodies. It is an organized arrangement of DNA and protein; the number of chromosomes per cell varies for different species. A chromosome contains a unit of inheritance; hence the chromosome is a collection of genes; the genetic information is stored in the chromosome, and the basic building block of GA is the gene [13]. The chromosomes are used to encode the search parameters information [15]. The cost function is assigned to each chromosome; according to this, the chromosomes are divided into best chromosomes and poor chromosomes.

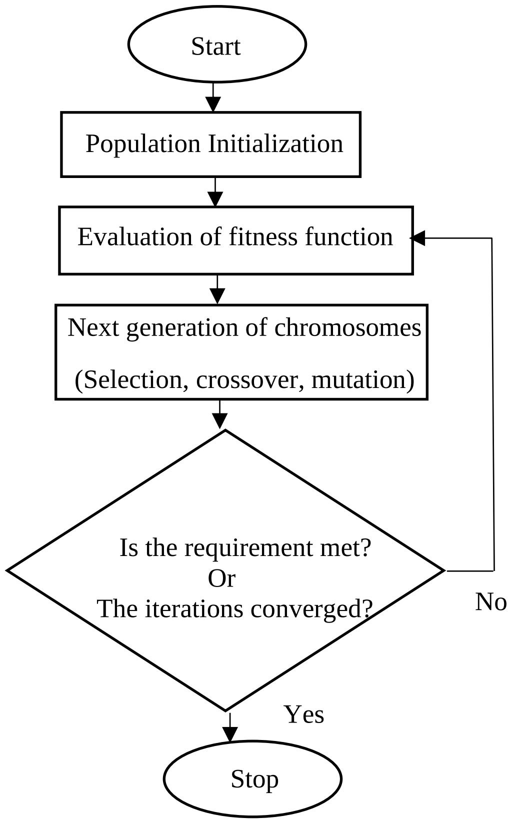

Fig. 1 Flow chart of genetic algorithm

2.2. Selection

The GA selects the best-fit chromosomes which are most suitable for the target function [15]. The best fit to the last fit will be assigned to the chromosomes based on the cost function evaluation ranking. There are several selection methods like Roulette-wheel selection (most fit chromosomes get more slices of roulette wheel than least fit ones), Elitist selection (selects only most fit ones), Cut-off selection (selects the chromosomes which fit above the chosen cut-off), etc. The unwanted chromosomes are discarded, and the best chromosomes are chosen for the next offspring, which are suitable for the target function. This process starts after determining the individual chromosome fitness and continues until a new population is formed [13].

2.3. Crossover

It is the operation of combining different parts of selected parent chromosomes to form new offspring [15]. It has different types like a single-point crossover, two-point crossover, uniform crossover, etc. GA can produce new chromosomes through this operation [15]. It is done by the hope that the new generation of chromosomes consists of all the good parts of the old parent chromosomes; hence new offspring is better [13].

2.4. Mutation

It is done after crossover. The mutation causes changes in the parts of chromosomes [15]. The chromosomes which contain good characteristics are not mutated; to preserve them for the next generations, these are called non-mutated chromosomes. The mutation rate is the rate at which minimum random changes can occur on chromosomes. If it is 100%, the whole chromosome will change if it is 0%, there will be no change in chromosome [13].

3. Formulation

3.1. Sum Pattern

The sum and difference patterns are used to steer the antennas in the desired direction of the target [16]. An array of elements gives better control of parameters to make the desired beam and improves directivity & gain, which may not be possible with a single antenna. Consider the array of N isotropic line sources placed from -1 to 1 array length. An example of a continuous line source array arrangement is shown in figure 2.

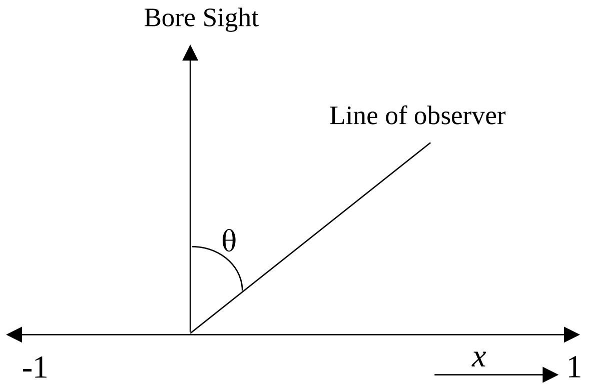

Fig. 2 Continuous line source

In a continuous line source, the elements are assumed to be infinite in a finite length of the line source, but such a line source is a theoretical concept. This is applicable only when radiating elements are assumed to be point sources. However, the continuous line source concept is considered by several researchers [17-20] who developed integral equations to evaluate radiation patterns from such radiating sources. In such expressions, x becomes a continuous variable, A(x) is a continuous amplitude distribution and similarly $\Phi(x)$ is a continuous phase distribution. The field pattern equation for a continuous line source array is given by [21].

$$E(u) = \int_{-1}^{1} A(x) e^{j2\pi L/\lambda[ux+\Phi(x)]} dx \quad (1)$$

As continuous line source is a theoretical concept, here we used a discrete array, the integration is replaced with the finite summation, and the continuous points are replaced by several numbers of elements in the array [21]. In the case of discrete arrays of isotropic radiators, x becomes x_n , A(x) becomes $A(x_n)$, $\Phi(x)$ becomes $\Phi(x_n)$. In discrete arrays, the spacing can be uniform or non-uniform, and it can be resonant or non-resonant spacing. $\frac{\lambda}{2}$ spacing of the radiating elements is resonant; the spacing other than $\frac{\lambda}{2}$ is non-resonant. In the arrays under consideration, there can be a center element, or there can be no center element. The spacing is usually symmetric from the array's centre, along with symmetric amplitude and phase distributions. The arrays with such consideration will also produce symmetrical radiation patterns. That means the side lobes on either side of the main beam are identical to their levels and sidelobe widths. The radiation pattern equation for the discrete array is given by [7]

$$E(u) = \sum_{n=1}^{N} A(x_n) e^{j2\pi L/\lambda[ux_n+\Phi(x_n)]} \quad (2)$$

Where;
$E(u)$ = Electric field pattern (v/m)
$A(x_n)$ = Amplitude excitation weights of the nth element
$2L/\lambda$ = Normalized length of the array
λ = Wave length, L = Length of the array
$u = sin\,\theta$
θ = angle of the line of the observer with a broadside
$\Phi(x_n)$ = Phase excitation of the nth element.

It is possible to optimize the spacing functions by the following techniques.

- Iterative technique
- Perturbation technique
- Dynamic programming technique
- Analytical programming technique
- Empirical programming technique etc.

Interestingly, Ishimaru [35] has reported a unique spacing function valid for arrays of odd and even elements in the array. For the sake of completeness, a few details of such an important spacing function are presented below. A radiation pattern of an array of N radiators is given by [23]

$$E(u) = \sum_{n=1}^{N} A(x_n) e^{j2\pi L/\lambda[ux_n]} \quad (3)$$

Where x_n represents the position of the n^{th} element. Rewriting equation (3) in the form of

$$E(u) = \sum_{n=1}^{N} f(n) \quad (4)$$

According to the following Poisson's sum formula [22].

$$\sum_{n=-\infty}^{\infty} f(n) = \sum_{m=-\infty}^{\infty} \int_{-\infty}^{\infty} f(v)\, e^{j2\pi mv}\, dv \quad (5)$$

It may be noted in the above expression LHS value summation extending from -∞ to ∞ and the RHS as ∞ to summation of an integral, where the integral is also indefinite. It is possible to write

$$E(u) = \sum_{m=-\infty}^{\infty} \int_{0}^{N} f(v)\, e^{j2\pi mv}\, dv \quad (6)$$

Using Dirac delta functions and making some mathematical manipulations from the equations (3), (4), (5) & (6), it is possible to write

$$E(u) = \sum_{m=-\infty}^{\infty} \int_{\epsilon}^{\epsilon+N} f(v)\, e^{j2\pi mv}\, dv \quad (7)$$

Where $0 < \epsilon < 1$

$$x = x(v) \quad (8)$$

$$x_n = x(n) \quad (9)$$

$$v = v(x) \quad (10)$$

$$n = v\,(x_n) \quad (11)$$

Using the steps described by Ishimaru [21], we can write

$$E(u) = \sum_{m=-\infty}^{\infty} (-1)^{m(N-1)} E_m(u) \quad (12)$$

$$E_m(u) = \frac{1}{2}\int_{-1}^{-1} A(x)\frac{dy}{dx}\left(e^{-j\Psi(x)+jm\pi N(y-x)} \times e^{j(u+m\pi N)x}\, dx\right) \quad (13)$$

$$u = ka \sin\theta$$

$$2a = x_N - x_0$$

$x=x(y)$ normalized source position function $-1 < x < +1$

$y=y(x)$ normalized source position function $-1 < y < +1$

Thus, the actual position of the nth element is

$$x_n = ax(y_n) \quad (14)$$

If N is odd, N = 2M+1

$$y_n = \frac{n}{M+\left(\frac{1}{2}\right)},$$

$$n = 0, \pm 1, \pm 2, \ldots, \pm M.$$

If N is even, N = 2M

$$y_n = \frac{n-\left(\frac{1}{2}\right)}{M} \qquad \text{for } n > 0,$$

$$y_n = \frac{n+\left(\frac{1}{2}\right)}{M} \qquad \text{for } n < 0,$$

It is obvious that the above expressions are written, one spacing function for odd numbers and another spacing function for even numbers, but it is possible to write the following single expression for a spacing function, valid for both odd and even element arrays. i.e., …

$$x_n = \frac{2n-N-1}{N} \quad (15)$$

Where x_n= Position of n[th] element in the array.

N = the total number of elements in the array.

n = the element number.

The normalized far field is

$$E_n(u) = \left|\frac{E(u)}{E(u)_{MAX}}\right| \quad (16)$$

The far-field in dB is given by

$$E(u) = 20 \log (E_n(u))\ dB \quad (17)$$

3.2. Difference Pattern

The difference pattern is a radiation pattern which contains a null in the boresight direction. On either side of the null, two major lobes of equal height will be in symmetric arrays. It can be generated from the discrete array equation shown in equation (1) by giving 180 degrees phase shift in one half of the array [21].

$$E_d(u) = \sum_{n=1}^{\frac{N}{2}} A(x_n) e^{j(2\pi L/\lambda[ux_n+\Phi(x_n)]+\alpha)} dx + \sum_{n=\frac{N}{2}}^{N} A(x_n) e^{j((2\pi L/\lambda[ux_n+\Phi(x_n)]+\alpha))} dx \quad (18)$$

Where α is an additional phase to produce the difference patterns to produce null in the bore sight direction. α should be 'π' for one-half of the array of elements, and it is '0' for the second half.

3.3. Design of SLS Difference Patterns from Sectorial Beam

As evident from the popular literature, difference patterns can be generated from the narrow beams by providing antiphase excitation to one-half of the array on a line source. But the requirement of the height of the difference lobes above the side lobes of the pencil beam cannot be maintained. Usually, the difference between the Side Lobe Level and the main difference lobe is about 8 db. In order to achieve this, it is required to produce a sector beam first and then convert it into difference patterns with the above-mentioned antiphase excitations. The so-called sector beams are produced from pencil beams by introducing an optimized phase distribution keeping the amplitude the same. As seen in the preceding sections, amplitude-only control generates sum patterns with symmetrical side lobes. However, additional phase distribution and fixed amplitude functions are required when sector beams are required. Such a phase function can be designed analytically using the stationary phase concept [17, 25]. This concept is widely used in signal processing. However, it is extended for the design of required phase distribution to produce sectorial beams where the beam has constant amplitude during the trade-in region, and low-level sidelobes exist in the trade-off region. The sectorial beams can be either symmetric or asymmetric, depending on the user's requirements.

3.4. Design of Phase Distribution

The relation between E-field produced from a continuous line source with a typical amplitude distribution is given by

$$E(u) = \int_{-L}^{L} a(s) e^{j\beta us}\, ds \quad (19)$$

Where u = sin θ, θ is the angle between the direction of propagation and normal to the array, $\beta = 2\pi/\lambda$, λ is the operating wavelength, and 2L is the length of the aperture. A typical geometry is shown in figure 2. If x=s/L, the line source extends from -1 to +1, and a(x) is amplitude distribution. Equation (19) becomes the following

$$E(u) = \int_{-1}^{1} a(x) e^{j\beta L u x}\, dx \quad (20)$$

The above a(x) can be written as

$$a(x) = A(x)\, e^{j[\Psi(x)+\Psi 1(x)]} \quad (21)$$

$$\text{Where} \quad \Psi(x) = \beta L\, \Phi(x) \quad (22)$$

From equations (19), (20), (21) and (22), we get

$$E(u) = \int_{-1}^{1} A(x) e^{j\beta L[ux+\Phi(x)]}\, dx \quad (23)$$

In order to explain the concept behind, x can be replaced by y, A(x) by B(y), βL by Ƞ, $[ux + \Phi(x)]$ by Z(y), the lower limit of the integral by y_1 and the upper limit by y_2 then equation (23) is simplified to equation (24)

$$F(Ƞ) = \int_{y1}^{y2} B(y) e^{j\beta L Ƞ Z(y)}\, dy \quad (24)$$

It may be noted that y_1 and y_2, B(y), and *Z(y)* are independent of *Ƞ*. If *Ƞ* becomes large, the integrand of equation (24) leads to rapid oscillations and cancels themselves for most of the range [25]. But when y is infinite in the neighbourhood of *y1* and *y2,* cancellation does not take place.

Over & above, when *Z(y)* has a minimum rate of variation, cancellation does not take place near the zeros of $\frac{\partial Z(y)}{\partial y}$ and hence they are called as stationary points.

3.5. Methods of Evaluation of Phase Function

According to energy relations [28], only one point in the aperture domain illuminates one point in the new domain. It is, therefore, possible to write the following expressions.

$$\frac{L}{\lambda}\int_{-\infty}^{\infty} |E_d(u)|^2 du = \int_{-\infty}^{\infty} A^2(x)\, dx \quad (25)$$

Or

$$\frac{L}{\lambda}\int_{-\infty}^{u} |E_d(u)|^2 du = \int_{-\infty}^{x} A^2(x)\, dx \quad (26)$$

Or

$$\frac{L}{\lambda}\int_{u}^{\infty} |E_d(u)|^2 du = \int_{x}^{\infty} A^2(x)\, dx \quad (27)$$

Or

$$\frac{L}{\lambda}\int_{u_1}^{u_2} |E_d(u)|^2 du = \int_{x_1}^{x_2} A^2(x)\, dx \quad (28)$$

Or

$$\frac{L}{\lambda}\int_{u_1}^{u} |E_d(u)|^2 du = \int_{x_1}^{x} A^2(x)\, dx \quad (29)$$

A change in the variable 'u' results in the corresponding change in the location of stationary points, and it is given by

$$\frac{\partial}{\partial x}[ux + \Phi(x)] = 0 \quad (30)$$

Thus gives

$$u = -\Phi'(x) \quad (31)$$

Assume the desired sector beam to be in the form of

$$E_d(u) = K \quad \text{for} \quad u_1 \le u \le u_2 \quad (32)$$

$u_2 - u_1$ = desired sectorial beam width.

Where K is a constant, one of the energy relations is given by

$$\frac{L}{\lambda}\int_{u_1}^{u_2} |E_d(u)|^2 du = \int_{-1}^{1} A^2(x)\, dx \quad (33)$$

The constant K is obtained from (33) and (34) i.e.

$$K^2 = C = \frac{\lambda}{L(u_2-u_1)}\left[\int_{-1}^{1} A^2(x)\, dx\right] \quad (34)$$

In order to solve the expression (31), a relation between *u* & *x* is obtained from the following.

$$\frac{L}{\lambda}\int_{-1}^{u} |E_d(u)|^2 du = \int_{-1}^{x} A^2(x)\, dx \quad (35)$$

$$\text{i.e.} \quad \frac{L}{\lambda} K^2[u+1] = \int_{-1}^{x} A^2(x)\, dx \quad (36)$$

$$\text{i.e.} \quad u = \frac{\lambda}{LC}\int_{-1}^{x} A^2(x)\, dx - \frac{LC}{\lambda} \quad (37)$$

$$\text{i.e.} \quad u = (u_2 - u_1)\frac{\int_{1}^{x} A^2(x)\, dx}{\int_{-1}^{1} A^2(x)\, dx} - \frac{1}{(u_2-u_1)}\int_{-1}^{1} A^2(x)\, dx \quad (38)$$

$$\Phi'(x) = \frac{1}{(u_2-u_1)}\int_{-1}^{1} A^2(x)\, dx + (u_2 - u_1)\frac{\int_{1}^{x} A^2(x)\, dx}{\int_{-1}^{1} A^2(x)\, dx} \quad (39)$$

In the above expression, A(*x*) is evaluated conventionally using Taylor's amplitude distribution or cosine on the pedestal. However, it is found from the literature that the resulting patterns are not optimum with such amplitude distributions.

To improve the pattern characteristics, an attempt is made in the present work to design amplitude distribution using a genetic algorithm. The amplitude distribution so determined is used to produce sector beams by introducing the evaluated phase function. The details of the genetic algorithm are presented in the preceding section.

4. Taylors Amplitude Distribution

Taylor's method of designing amplitude distribution is confined to the design of line sources. A line source is an array of finite lengths with an infinite number of elements. It means there is no spacing between the elements; hence it is an ideal array antenna. However, the resultant amplitude distribution will be continuous in nature, characterized by the maximum value of the center tapering towards the end. Introducing such an amplitude distribution to the line source yields a radiation pattern with a narrow lobe in the boresight direction with a set of minor lobes on either side.

The Taylor expression for the desired pattern is given by [37]

$$E(u) = \cosh(\pi A)\frac{\sin(u)}{u}\prod_{n=1}^{\bar{n}-1}\left[\frac{1-\frac{(u)^2}{\sigma^2\ \pi^2\ \left\{A^2\ +\left(n-\frac{1}{2}\right)^2\right\}}}{\left\{1-\frac{(u)^2}{(\pi n)^2}\right\}}\right] \quad (40)$$

Where $\bar{n}$ is an integer, u = $\frac{2L}{\lambda} sin\Phi$, Φ is the angle measured from maximum radiation. 2L is the array length, and A is an adjustable parameter having the property that cos(πA) is the side lobe ratio.

$$\sigma = \frac{\bar{n}}{\left\{\left[A^2\ +\left(n-\frac{1}{2}\right)^2\right]^{1/2}\right\}} \quad (41)$$

It has been possible to make the desired number of sidelobes at equal heights by choosing the value of $\bar{n}$. for example, if $\bar{n}$ is 5, there will be 4 side lobes of equal height. The remaining side lobes decay exponentially.

Using equation (40), the amplitude distribution of an array is found by using Woodward's method given by

$$A(x) = \sum_{n=-\infty}^{\infty} a_n e^{-jn\pi x} \quad (42)$$

Where x=X/L, X being a variable point on the array. The pattern E(u) related to A(x) is given by

$$E(u)= \int_{-1}^{1} A(x)e^{jux}\, dx \quad (43)$$

Using expressions (42) and (43), we get

$$E(u) = \sum_{n=1}^{\infty} a_n \frac{\sin(u-n\pi)}{(u-n\pi)} \quad (44)$$

Thus gives

$$a_n = E(u)|_{u=n\pi}$$

Therefore, the expression (44) reduces to

$$E(u) = \sum_{n=1}^{\infty} E(n\pi) \frac{\sin(u-n\pi)}{(u-n\pi)} \quad (45)$$

The aperture distribution is obtained in the form of

$$A(x)= a_0+\sum_{n=1}^{\infty} 2a_n \cos(n\pi x) \quad (46)$$

or

$$A(x)= E(0)+2\sum_{n=1}^{\infty} E(n\pi)\cos(n\pi x)$$

and $E(n\pi)$=0 for n≥$\bar{n}$

In fact, the above distribution can be discretized by taking amplitude values at the sampled locations of the elements.

5. Results and Discussion

In the present work, a Genetic algorithm is developed and implemented using MATLAB software to find out the excitation levels of each radiator, which intern gives a minimum cost function. The cost function represents the minimum Side Lobe Level (SLL) [13]. The variables in the GA are population size, mutation rate, maximum generations, maximum function, and cost function [30]. The desired SLL is set at -35 dB, and the remaining parameters are assigned randomly to evaluate the cost function. This procedure is valid for any array containing 'N' number of elements.

The random values are passed on to the parameters of the genetic algorithm to estimate the fitness function. Natural selection is to retain half of the best chromosomes and leave the remaining half of the unhealthy ones [31]. Then the selected healthy chromosomes are combined to generate the next offspring. This leads to the existence of only the best chromosomes in new breeding.

In the present work, arrays with different numbers of elements are considered for the design. It is evident from the preceding sections that a pattern with one main narrow beam by introducing an optimized phase function. For that, the sector beam is converted into Side Lobe Suppressed (SLS) difference patterns by an additional phase of 'α.' The Genetic Algorithm is used for amplitude distribution, and the stationary phase concept is used for phase distribution. This design is unique and, to the best of the author's knowledge. The useful results are produced for the first time using the above methods.

The design involves an analytical approach as well as a numerical approach. The universal approach can be applied to design any type of array while saving a lot of computational time.

The numerically computed results for the variation of amplitude distribution ($A(x_n)$) and phase distribution ($\Phi(x_n)$) along the array for N= 40 & 80 are presented in figures 3 to 6. The amplitude distributions are normalized to vary between 0 to 1. The phase distribution for sectorial width of 0.6 is presented.

Moreover, the two distributions mentioned above obtained from the present design are compared with those of Taylor's distributions. Introducing the above distributions in the expressions of field strength patterns, the pattern characteristics are numerically evaluated, and results are presented in figures 7 to 14.

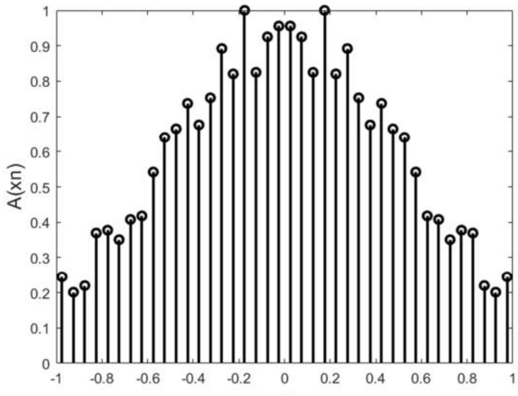

Fig. 3 Normalized amplitude distribution for N = 40 elements

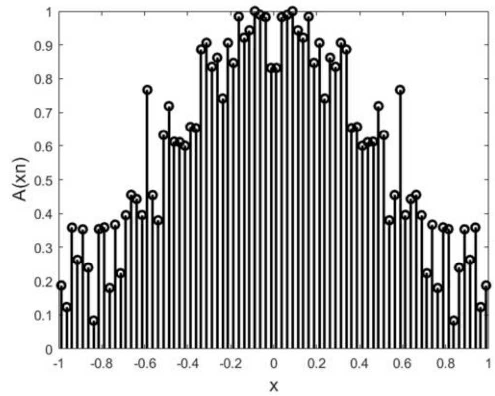

Fig. 4 Normalized amplitude distribution for N = 80 elements

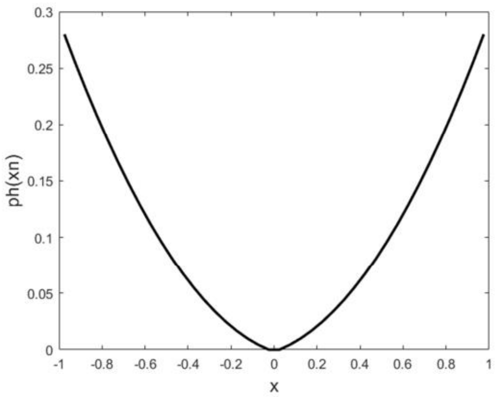

Fig. 5 Phase distribution for N = 40 elements

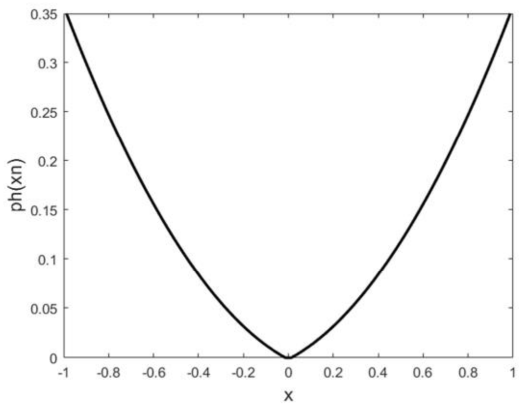

Fig. 6 Phase distribution for N = 80 elements

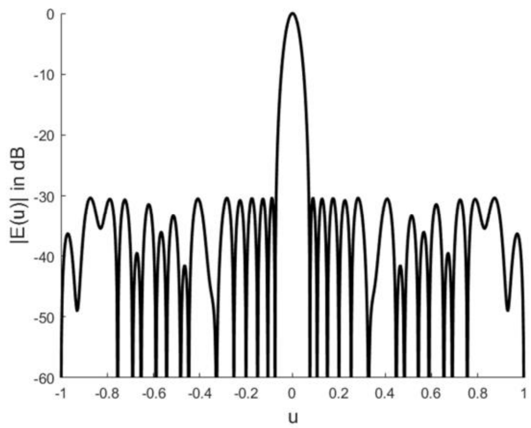

Fig. 7 Sum pattern using GA with amplitude-only control for N = 40 elements

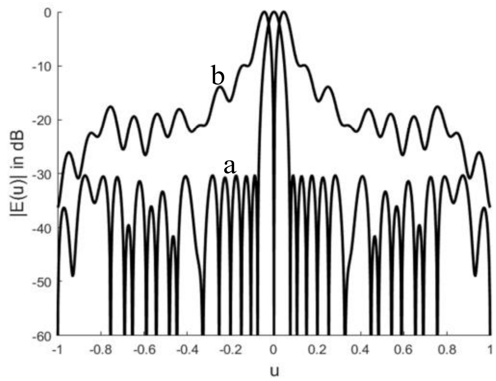

Fig. 8 Normalized radiation pattern using GA with amplitude-only control for N = 40 elements (a) Sum pattern (b) SLS difference pattern

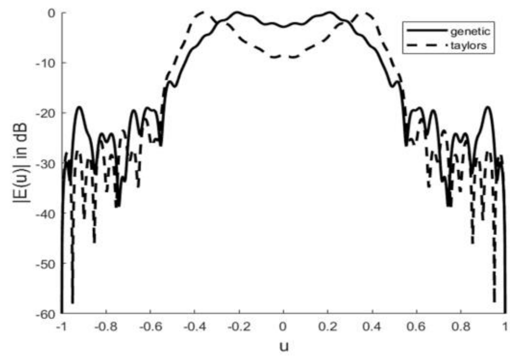

Fig. 9 Sector beam for N = 40 elements

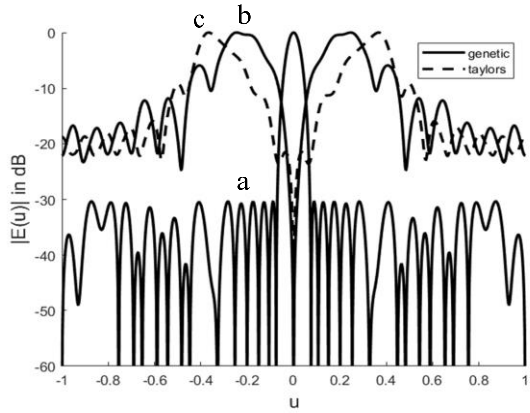

Fig. 10 Normalized radiation pattern for N = 40 Elements (a) Sum pattern using GA with amplitude only control (b) SLS difference pattern using GA with amplitude and phase control for u = 0.6 (c) SLS difference pattern using taylor's with amplitude and phase control for u = 0.6

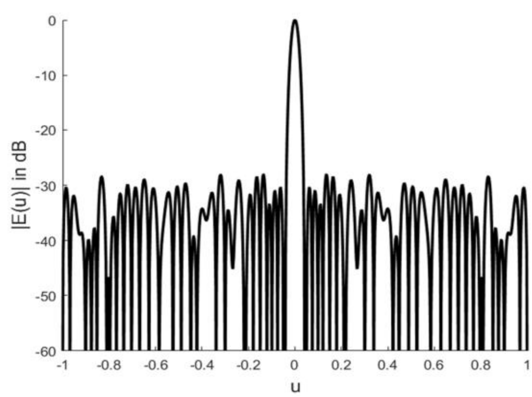

Fig. 11 Sum pattern using GA with amplitude-only control for N = 80 elements

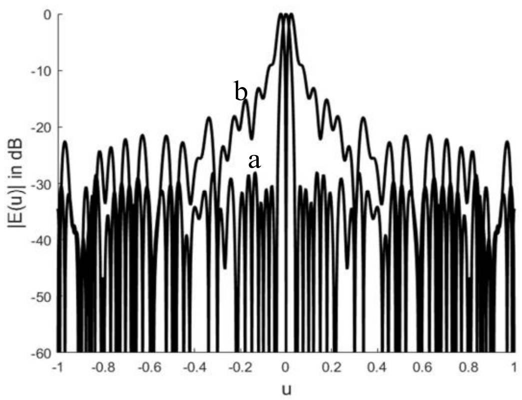

Fig. 12 Normalized radiation pattern using GA with amplitude only control for N = 80 elements (a) Sum Pattern (b) SLS difference pattern

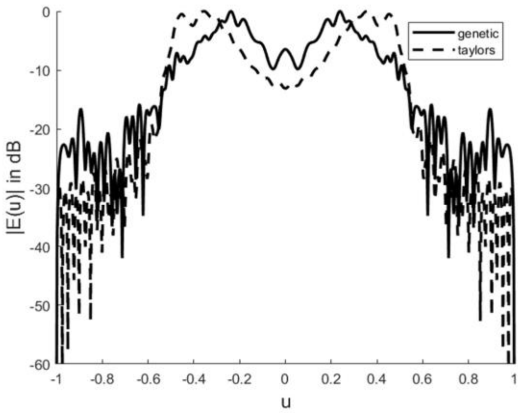

Fig. 13 Sector beam for N = 80 elements

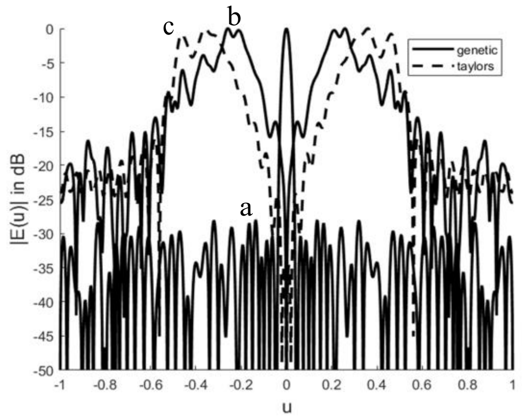

Fig. 14 Normalized radiation pattern for N = 80 elements (a) Sum pattern using GA with amplitude only control (b) SLS difference pattern using GA with amplitude and phase control for u = 0.6 (c) SLS difference pattern using Taylor's with amplitude and phase control for u = 0.6

It is evident from the results that it has been possible to change the narrow beam to a sector. The sector to difference patterns with the additional phase weights for each element in the array are found to be practically realizable by using either analog phase shifters or digital phase shifters. In the present work, the phase weights are calculated using the stationary phase concept and require amplitude weights generated using the genetic algorithm and Taylor method. The sector beams obtained using GA are flatter in trade in the region than those of sector beams obtained using Taylors.

The difference patterns obtained after the addition of phase weights a as well can suppress the effect of side lobes as the height of the difference lobes is more than 8 dB above SLL. In the case of fast scanning applications, 4-bit digital phase shifters are found to yield good results. These patterns are widely used in IFF (Identifying Friend or Foe) applications. It may be brought to the notice of antenna users that; the so-called sum and difference patterns are generated from two different antennas [32]. However, in the present work, only one antenna can produce both patterns and hence the results are very useful as they met all the requirements of IFF applications.

6. Conclusion

A genetic algorithm is one of the state-of-art algorithms for optimizing any parameters in a given system. It is developed for the design of antenna arrays for pattern synthesis. To compare the present results on input excitations, sum patterns, sector beams, and difference patterns are compared with those of Taylor's distribution. It is found from the results of the Genetic Algorithm that each pattern presented is technically and practically useful for antenna designers. Although the results are presented for N = 40, 80, the method can be extended for any array type. The array can be linear, nonlinear, or even can be planar.

Acknowledgments

The authors express their gratitude to prof. Mukti Mishra, president and prof. DN Rao, Vice president of centurion university, to support the present work.

References

[1] G.S.N Raju, Antennas and Wave Propagation, Pearson, 2018

[2] Constantine A. Balanis, *Antenna Theory: Analysis and Design*, John Wiley & Sons, 2009. [Google Scholar] [Publisher Link]

[3] Arnulfo R. Gutiérrez et al., "Non-Uniform Antenna Array with Non-Symmetric Feeding Network for 5G Applications," *IEEE Antennas and Wireless Propagation Letters*, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[4] Ronghong Jin et al., "Research on Planar Antenna Arrays," *2014 International Workshop on Antenna Technology: Small Antennas, Novel EM Structures and Materials, and Applications (iWAT)*, pp. 140-142, 2014. [CrossRef] [Publisher Link]

[5] Ming Li et al., "Low Sidelobe Synthesis of Dipole Arrays by Element Orientation Selection Using Binary Codec Genetic Algorithm," *2017 11th European Conference on Antennas and Propagation (EUCAP)*, 2017, pp. 2838-2840, 2017. [CrossRef] [Google Scholar] [Publisher Link]

[6] MohammadRezal Ahangiri, Mohsen Kaboli, and Seyed Abdullah Mirtaheri, "Design Beamforming Network of Linear Array for Base Station Antennas at 1.71-2.69 GHz by Using Genetic Algorithm," *Electrical Engineering (ICEE), Iranian Conference on*, pp. 621-626, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[7] Sudheer Kumar Terlapu, and G. S. N. Raju, "Synthesis of Sector Beams from Array Antennas Using Real Coded Genetic Algorithm," *Advances in Intelligent Systems and Computing*, vol. 542, pp. 503-511, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[8] Lukasz A. Greda et al., "Beamsteering and Beamshaping Using a Linear Antenna Array Based on Particle Swarm Optimization," *IEEE Access*, vol. 7, pp. 141562-141573, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[9] Samar Ibrahim Farghaly et al., "Pencil and Shaped Beam Patterns Synthesis Using a Hybrid GA/l_1 Optimization and its Application to Improve Spectral Efficiency of Massive MIMO Systems," *IEEE Access*, vol. 9, pp. 38202-38220, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[10] Masashi Yamamoto et al., "Simple Design Method for Cosec Square with Null-Fill in Equispaced Linear Array," *2017 International Workshop on Electromagnetics: Applications and Student Innovation Competition*, pp. 160-161, 2017. [CrossRef] [Google Scholar] [Publisher Link]

[11] S. J. Blank, and M. F. Hutt, "On the Empirical Optimization of Antenna Arrays," *IEEE Antennas and Propagation Magazine*, vol. 47, no. 2, pp. 58-67, 2005. [CrossRef] [Google Scholar] [Publisher Link]

[12] Chirappanath Albert et al., "Comparative Analysis of Antenna Array Radiation Patterns Under the Influence of Number of Elements and Spacing between the Elements with Uniform and Non-uniform Excitations," 2017. [CrossRef]

[13] Rajya Lakshmi Valluri, and G. Raju, "Amplitude Only Pattern Synthesis of Arrays Using Genetic Algorithms," *International Journal of Engineering Science and Technology*, vol. 3, no. 5, 2011. [Google Scholar]

[14] R. Surendiran, and K. Alagarsamy, "An Extensive Survey on Mobile Security and Issues," *International Journal of Computer and Organization Trends*, vol. 2, no. 1, pp. 23-28, 2012. [CrossRef] [Publisher Link]

[15] L. Mukhanov, D. S. Nikolopoulos, and G. Karakonstantis, "DStress: Automatic Synthesis of DRAM Reliability Stress Viruses using Genetic Algorithms," *2020 53rd Annual IEEE/ACM International Symposium on Microarchitecture (MICRO)*, pp. 298-312, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[16] Xiangtao Li, Shijing Ma, and Guifu Yang, "Synthesis of Difference Patterns for Monopulse Antennas by an Improved Cuckoo Search Algorithm," *IEEE Antennas and Wireless Propagation Letters*, vol. 16, pp. 141-144, 2017. [CrossRef] [Google Scholar] [Publisher Link]

[17] T. T. Taylor, "Design of Line-Source Antennas for Narrow Beamwidth and Low Side Lobes," *Transactions of the IRE Professional Group on Antennas and Propagation*, vol. 3, no. 1, pp. 16-28, 1955. [CrossRef] [Google Scholar] [Publisher Link]

[18] R. Elliott, "Design of Line-Source Antennas for Sum Patterns with Sidelobes of Individually Arbitrary Heights," *IEEE Transactions on Antennas and Propagation*, vol. 24, no. 1, pp. 76-83, 1976. [CrossRef] [Google Scholar] [Publisher Link]

[19] K V S N Raju, and G S N Raju, "Comparative Studies on the Radiation Patterns of the Line Source and Discrete Arrays," *2006 9th International Conference on Electromagnetic Interference and Compatibility*, pp. 530-533, 2006. [Google Scholar] [Publisher Link]

[20] P. V. Sridevi et al., "Method of Generation of Sum and SLS-Type Difference Patterns," *Microwave and Optical Technology Letters*, vol. 7, pp. 559 – 563, 1994. [CrossRef] [Google Scholar] [Publisher Link]

[21] M. Vamshi Krishna, G. S. N. Raju, and S. Mishra, "Generation of Low Side Lobe Difference Pattern using Nature Inspired Metaheuristic Algorithms," *International Journal of Computer Applications*, vol. 143, 2016. [CrossRef] [Google Scholar] [Publisher Link]

[22] Dr. Thota Vidhyavathi, "Amplitude and Phase Synthesis of Linear Array for Sector Beams using Modified Harmony Search Differential Evolution Algorithm," *SSRG International Journal of Electronics and Communication Engineering*, vol. 3, no. 8, pp. 20-27, 2016. [CrossRef] [Google Scholar] [Publisher Link]

[23] A. Ishimaru, "Theory of Unequally Spaced Arrays," *IRE Transactions on Antennas and Propagation*, vol. 10, no. 6, pp. 691-702, 1962. [CrossRef] [Google Scholar] [Publisher Link]

[24] P.N. Morse and H. Feshbach, *Methods of Theoretical Physics*, LIC Gratv-Hill Book co., p. 166, 1953.

[25] Sudhakar Alapati et al., Optimized Ramp Patterns, vol. 73, pp. 1-8, 2000.

[26] Dr.R.P.Jayaraj, and H.Regina, "Design of Small Integrated Antenna for Peer to Peer Network," *SSRG International Journal of Mobile Computing and Application*, vol. 3, no. 1, pp. 9-11, 2016. [CrossRef] [Publisher Link]

[27] F.W.J. Olver, *Asymptotic and Special Functions*, Tata Mc Graw – Hill, New Delhi, 1974. [Publisher Link]

[28] C.E. Cook, and M.Bern Field, *Radar Signals*, NY, Academic Press, 1967. [Google Scholar]

[29] R. Surendiran, and K. Alagarsamy, "Privacy Conserved Access Control Enforcement in MCC Network with Multilayer Encryption," *International Journal of Engineering Trends and Technology*, vol. 4, no. 5, pp.2217-2224, 2013. [CrossRef] [Google Scholar] [Publisher Link]

[30] Smita Banerjee, and Ved Vyas Dwivedi, "Linear Antenna Array Synthesis to Reduce the Interference in the Side Lobe Using Continuous Genetic Algorithm," *2015 Fifth International Conference on Advances in Computing and Communications (ICACC)*, pp. 291-296, 2015. [CrossRef] [Google Scholar] [Publisher Link]

[31] Xueqin Mi et al., "An Efficient Optimization Algorithm Based on Characteristic Mode Method and Genetic Algorithm for Tightly Coupled Antenna Array," *2020 Cross Strait Radio Science & Wireless Technology Conference (CSRSWTC)*, pp. 1-3, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[32] Merrill Skolnik, *Radar Handbook*, McGraw Hill, 2008. [Google Scholar]

[33] Pramod Kumar, Ashutosh Kedar, and N. K. Vishwakarma, "Genetic Algorithm Aided Synthesis of Low SLL Antenna Array Utilizing Position Optimization based on Zoning Technique," *2018 IEEE Indian Conference on Antennas and Propogation (InCAP)*, pp. 1-4, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[34] A. Ishimaru, and G. Held, "Analysis and Synthesis of Radiation Patterns from Circular Apertures," *Canadian Journal of Physics*, vol. 38, no. 1, pp. 78-99, 1960. [CrossRef] [Google Scholar] [Publisher Link]

[35] Jetti Babu, and G.S.N. Raju, "Generation of Cosecant Beams From Circular Arrays," *AEU - International Journal of Electronics and Communications*, vol. 67, no. 2, pp. 81–87, 2013. [CrossRef] [Google Scholar] [Publisher Link]