Genatic Algorithm for Reducing the Side Lobe Level of Main Beam of Uniformly Excited Time Modulated Linear Array Antenna

S. K. Mandal, G. K. Mahanti, Rowdra Ghatak

Abstract* - The Side Lobe Level (SLL) of the main beam of a uniformly excited time modulated antenna array is reduced to less than -55 dB by using Genetic Algorithm (GA). For a uniformly excited linear antenna array the maximum side lobe level is ~ -13.5 DB. In this work the uniformly excited antenna array is first time modulated and then the on-time sequences of each of the array elements are optimized by applying GA to get the desired result.

***Index Terms*— Time Modulated Linear Array (TMLA), Side lobe level (SLL), Side band radiation (SBR), Genetic Algorithm (GA).**

I. INTRODUCTION

Usually, three parameters, amplitude, phase and the inter element spacing's of array elements are adjusted to get the desired radiation pattern of the antenna array. Amplitudes and inter element spacing's are tuned to reduce *SLL* whereas phase to rotate the maximum radiation direction. Array with non-uniform amplitude; like, Binomial distribution can give radiation pattern without side lobe level (*SLL*) whereas Tschebyscheff distribution with any desired SLL. But they offer high dynamic range ratio of amplitude for which feeding network becomes complex and difficult to realize. Also the tapered amplitude distribution of the array elements may cause several errors such as systematic errors and random errors. Thus, uniform antenna array is easy to design and offer minimum beam-width. But due to relatively higher (~ -13.5 dB) side lobe level *(SLL)* it becomes impractical for long distance communication. In time modulated antenna array (*TMAA*) in addition to above mentioned three parameters, a fourth parameter *'time'* is used to design the antenna array. To introduce time as a fourth antenna design parameter, high frequency *r.f.* switches are connected to each of the array elements. Now the r. f. switches are periodically *'on'* (short circuited) and *'off'* (open circuited) for predetermined time duration with a specific time period *'T_P'*. Thus, the switch connected to m^{th} element *'on'* (active) for ($T_{on}^{m} \le T_P$) time durations at each (T_P) time duration. Where superscripts denotes the 'mth element of the array and T_P is the modulation period. Thus, array elements are instead of acting continuously, active periodically for predefined time duration at each specific interval of time, T_P. Antenna array with such periodical switching *'on – off'* of the array elements with a predetermined time period is known as time modulated antenna array (TMAA). When the time modulation technique is applied to an antenna array with uniform exciting amplitude of the array elements and uniform spacing between two consecutive array elements, the resultant antenna is known as time modulated linear array (TMLA) antenna. Progressive on-time duration of array elements is used for simultaneously electronic scanning at different frequency [2]. Kummer et al. [3] developed a time modulated antenna array of an eight elements slotted waveguide and acquired low and ultra low *SLL* (~ -39.8 dB) by using simple on-off switching of array elements with some preset sequence. However the main problem of TMAA is that the radiated signal not only contain the signal of desired frequency but also contain signals of different harmonics of the time modulating frequency ($f_P = 1/T_P$) which are called side band radiation (*SBR*) i.e., sideband signals. Hence a part of the total radiated signal power is radiated at different sidebands. In 2002, Yang et al. [4] optimized the switch on time instants of the array elements by applying differential evolutionary (*DE*) algorithm to suppress the side-band radiation (*SBR)* of a time modulated linear array (*TMLA)*. In [5], simulated annealing technique is employed to retain the side lobe level by reducing the unwanted harmonics. An expression for the total power in the side band of a TMAA has been derived and efficiency is calculated in [6]. Particle Swarm Optimization (PSO) is used in [7] as a searching algorithm in TMLAs to increase the stability of the radiation pattern. Without phase shifter, electronically, the radiation beam is guided by controlling the switch on time duration of the array elements in the first side band of TMLA in [8]. By using non-uniform amplitude TMLAs, less number of elements may give the desired far field radiation pattern [9]. In [10], the switch on-off time instances are applied to simultaneously steer the harmonic beam and reduce the side lobe level. A. Tennant designed a two element direction finding time modulated array in [11]. In this work, a thirty element uniformly excited linear array is considered and the Global search and optimization algorithm, GA is used to lower the side lobe level of the main beam to below -55dB. To get the desired result, GA is applied to optimize the on-time i.e., active time duration of each array elements keeping the amplitude of the array elements constant. Rest of the paper is arranged as follows.

Manuscript received December 09, 2011.

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The theory of TMAA is represented in section II. Section III expresses the incorporation of GA in TMAA optimization. The results of this work are discussed in section IV and conclusion is drawn in section V.

II. THEORY OF TIME MODULATED ANTENNA ARRAY

Let *N* number of mutually uncoupled isotropic radiator placed along the x-axis starting from the origin with the same spacing, d_0 between two consecutive elements as shown in Fig. 1. If A_m be the amplitude of each isotropic element, the far field radiation pattern in the XZ – plane (One of the vertical principle plane) of the array in the free space can be obtained with the array factor (AF') as given in (1), [1].

$$AF' = \sum_{m=0}^{N-1} A_m e^{j(\omega_0 t + mkd_0 \cos\theta)} \qquad (1)$$

Where, $\omega_0 = 2\pi f_0 = 2\pi/T_0$, the angular frequency (rad / sec), f_0 , the operating frequency (Hz), T_0, the time period of the operating signal, $k = 2\pi/\lambda$, the wave number; $m = 0, 1, \ldots\ldots, (N-1)$, any integer between 0 to $(N-1)$; and θ, the angle made by the line joining the observing point and the origin with the x-axis as shown in Fig.1.

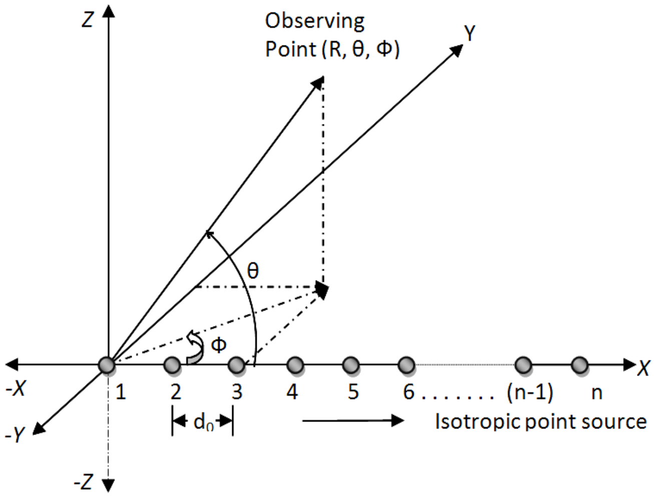

Fig. 1 Basic antenna array of N elements with uniform spacing, d_0.

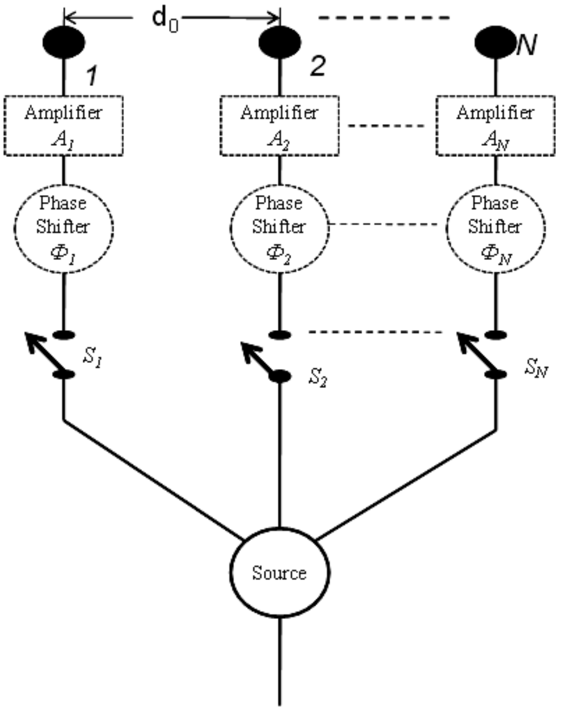

Fig. 2 Block diagram of Time Modulated Antenna Array

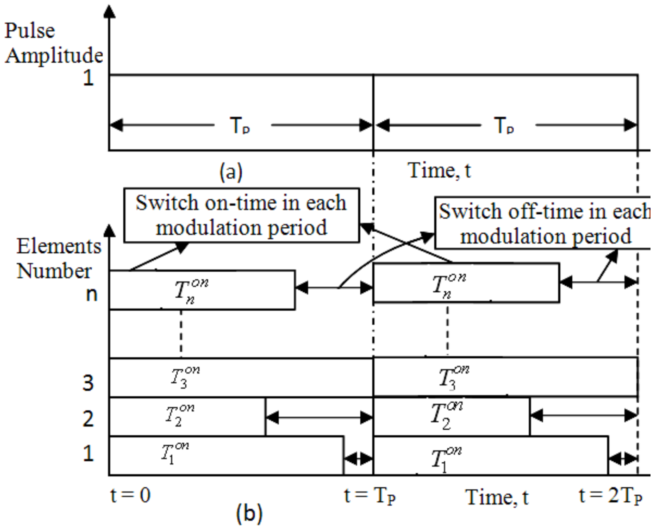

Fig. 3(a) Unit Pulse of periodicity T_P; (b) On-Off time duration off each element for one time modulation period T_P and it is repeated at every T_P time interval.

Now instead of exciting each antenna element of the array continuously, the array elements are periodically active and inactive for predetermined time duration with a period 'T_P'. To control the time duration (T_{on}^m) for which each array elements are on (active), all of the array elements are connected individually to RF switches i.e., *N* elements are connected to N number of RF switches as shown in Fig. 2. Now, the switches are on and off periodically with a time period T_P. Hence, at each period, the time duration by which a switch is on, the array element connected to that switch is active for that time duration only otherwise it will be inactive. Assuming all the switches are on (short circuited) at the same time at $t = 0$ or at the beginning of each period '$n*T_P$' and each switch remains short circuited for their specific time duration as shown in Fig.3 (b) and the switches are open circuited after their corresponding on-time (T_{on}^m). The ON-OFF time duration of each switch for 1st two time period only is shown in Fig. 3(b). The switch which is on for whole time period T_P, can be considered as a unit pulse of period T_P, as shown in Fig. 3(a). Hence if the m^{th} element is periodically on for T_{on}^m time duration at every T_P interval of time ($T_{on}^m \leq T_P > T_0$), the modified array factor AF can be expressed as given in (2), [3].

$$AF(\theta,t) = \sum_{m=0}^{N-1} A_m U_m(t) e^{j(\omega_0 t + mkd_0 \cos\theta)} \qquad (2)$$

Where $U_m(t) = 1 \text{ for } 0 \leq t \leq T_{on}^m$

$= 0 \text{ for } t \geq T_{on}^m$

For each time interval T_P.

Hence $U_m(t)$ be a time periodic function of periodicity T_P of unit amplitude. The frequency response of the array factor after time modulation can be obtained by applying Fourier series method into the equation (2). In the case of TMLA defined in section-I, the amplitude of each element is uniform and all elements are operated in same phase. Hence all the dotted boxes in Fig.2 representing amplifier and phase shifter can be omitted. Thus, to design N-element TMLA, N number of r.f. switches is required only. Considering amplitude of all the array element is equal to unity i.e., all $A_m = 1$, the changed array factor expression can be written as

$$AF_r^{'}(\theta,t)=e^{j2\pi(f_0+rf_p)t}\sum_{r=0}^{\infty}\sum_{m=0}^{(N-1)}C_{mr}e^{i\phi_m} \qquad (3)$$

Where $\phi_m = kmd_0\cos\theta$; the linear phase difference of each element (rad) and C_{mr} is the Fourier coefficient at the r^{th} harmonics of modulation frequency for the m-th element and is given in (4).

$$C_{mr}=W_m\frac{\sin(r\pi f_p W_m)}{r\pi W_m}e^{-jr\pi W_m} \qquad (4)$$

Where $W_m=\frac{T_{on}^m}{T_p}$, normalized on time of the m^{th} element.

From (3), it is clearly understood that the signal is not only radiated at the operating frequency but also the signals are radiated into the harmonics of the modulating frequency. Hence the array factor at the r^{th} harmonics can be written as

$$AF_r(\theta,t)=e^{j2\pi(f_0+rf_p)t}\sum_{m=0}^{(N-1)}C_{mr}e^{i\phi_m} \qquad (5)$$

Hence from (4) & (5) the array factor at the fundamental frequency i.e. at operating frequency (for $r=0$) can be obtained as

$$AF_{r=0}(\theta,t)=e^{j2\pi f_0 t}\sum_{m=0}^{(N-1)}W_m e^{i\phi_m} \qquad (6)$$

Equation (6) represents that the average on time of each elements are the amplitude coefficient of that elements. Hence by applying time modulation to uniform linear array we may optimize the amplitude coefficients of each element of the TMAA for obtaining the desired far field radiation pattern as it is done for Chebyshev. But the major problem of TMAA is its sideband radiations (*SBRs*). The *SBRs* can also be minimized by applying different evolutionary algorithm and changing the cost function of the corresponding problem. In this work we are only concentrating to reduce the *SLL* of the main beam (for $r=0$) of the radiation pattern (i.e., the radiation pattern of TMAA at operating frequency).

III. INCORPORATING GENETIC ALGORITHM IN OPTIMIZATION OF TMLA

Genetic Algorithms (GAs) is a stochastically global search and optimizing evolutionary algorithm. The principles of genetic recombination and evolution in nature are modeled in Genetic algorithm (GA). Like nature, the basic building blocks of GA are gene. The fundamental details of GA can be found in [10 -13]. The formulation that connects problem space and solution space are given here in.

A. Function and Parameters to be optimized GA finds out the values of a set (N no.) of parameters of the given function (*f*) which may give the best desired result. The best result may be the maximum or minimum of the function. Also, it is very important to identify the parameters which are independently effect the function value of the problem being considered. When a function (*f*) is dependent on *N* independent parameters, each value of the function for different value of parameters represents different points in the space of N-dimensional coordinate system. Hence the variation of the parameters value within a specified range gives the different value of the function within the region surrounded by the maximum and minimum value of the parameters. Change in parameters value between its specified ranges searches the desired function value within the region under consideration. Now the traditional gradient based searching method has a tendency to quickly converge into its optimal solution locally and also it cannot be applied into the points where it is not differentiable or it has any discontinuity. Again, the direct search method is slow, as, to get the optimal solution too many function values are to be calculated. Genetic Algorithm (GA) searches stochastically and randomly through whole region in space under consideration to get optimal solution. In this work, the normalized array factor ($AF_{r=0}$) of TMAA is the function which is dependent on the normalized switch on-time, $W_m=\frac{T_m}{T_p}$ of the array elements independently. Hence for N element TMAA, *N* number of normalized on times, W_m (for $m = 1, 2\ldots N$) are the parameters which are optimized to reduce and obtain different value of SLL of $AF_{r=0}$. N=30 is considered in this problem. The desired set of parameters value is achieved through the search space bounded by the whole range of W_m, (0, 1). Each set of W_m can be thought as a solution of the function $AF_{r=0}$.

B. Initial Population Unknown solution of $AF_{r=0}$ at which the function will have the desired SLL, is searched through the complete search region. Initially 50 points (a set of solution) are randomly specified to explore the set of parameters value which will give the desired result, called initial population. Each set of solution is normalized switch on time of the 30 elements. 50 set of parameters is a [50×30] matrix which is generated randomly.

C. Fitness Scaling Fitness values of the entire individual solutions are scaled in such a way that the scaled values are proportional to 1/√k (k, rank position) and all of its summation is equal to number of parents required for the next generation. The solution with lowest fitness value is ranked as ‘1’ and next lowest as ‘2’ and so on.

D. Selection The scaled values are arranged in a line such that each fragment of line is proportional to scaled value of parent solution. The line is divided into a number of steps. In each steps a random number less than step size selects location on the line. Parents with scaled value falling under the line are selected.

E. Generation Searching starts with 50 initial populations which may not give the desired result and it is continued hoping for obtaining the best result by generating same numbers of new solutions in each generation, called Childs. Two best solutions are directly promoted to next generation.

85% of remaining (48) new solutions (childs) are generated by crossover (0.85 × 48 ~ 41) and 7 by mutation operation. In cross over operation two parents are selected randomly. A random number r ($1 \leq r \leq N$) is generated. First *r* parameters of first parents and (N – r) parameters of the second parents and first r parameters of second parent and last (N – r) parameter of 1st parent are recombined to form two new childs. In mutation, a fraction of the total parameters of a solution selected uniformly with mutation probability and the selected parameters are replaced by a number generated randomly within the range of parameter value (0, 1).

F. Convergence Criterion The code of the cost function used in the problem is given below.

`if` SLL_{max} `<` $SLL_{desired}$`,Cost = 0;`
`else` $Cost=abs(SLL_{max} + SLL_{desired})$`;end`

Where SLL_{max} and $SLL_{desired}$ be the actual and desired maximum SLL of the main beam of TMAA. The program is run for 1000 iterations. The selection of the best solution and the child generation continues till the desired result has been obtained or the predefined number of iteration is reached.

IV. RESULTS AND DISCUSSION

The normalized switch on time duration of a 30 element antenna array for the desired result is presented in table 1. The plot of normalized array factor of a uniformly excited TMLA using ON time duration of Table 1 is shown in Fig. 3. The maximum SLL that is obtained in the main beam of TMLA is -55.6 dB. And its FNBW is also measured as 16.8^0. Maximum power at first and second side bands with respect to the main beam maximum power is also measured as -7.3 and -12.9 dB respectively.

TABLE I on time duration of each element

m^{th} element	d_m
1	0.0122
2	0.0236
3	0.0428
4	0.0730
5	0.1100
6	0.1601
7	0.2158
8	0.2827
9	0.3519
10	0.4247
11	0.4986
12	0.5663
13	0.6294
14	0.6800
15	0.7225
16	0.7474
17	0.7578
18	0.7479
19	0.7202
20	0.6760
21	0.6160
22	0.5454
23	0.4625
24	0.3814
25	0.2966
26	0.2219
27	0.1536
28	0.0986
29	0.0571
30	0.0320

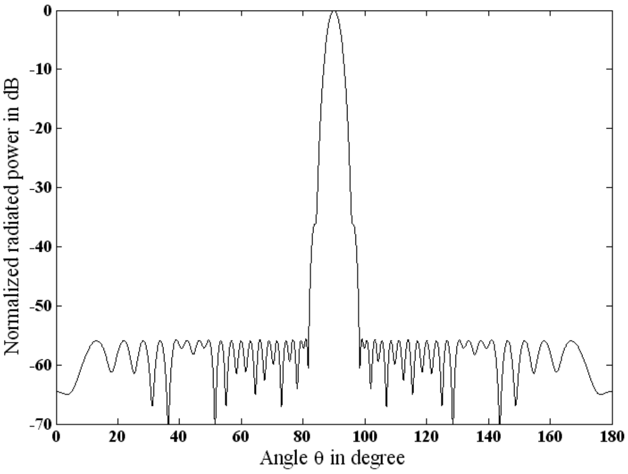

Fig. 4 Normalized array factor of a uniformly excited TMLA with on time of table 1

V. CONCLUSIONS

Thus the maximum SLL of the main beam of uniformly excited TMAA is reduced to -55.6 dB. In this work, only the radiation at operating frequency is considered. However the reduction of SLL at the operating frequency may lead to increase in SBR. SBR can be minimized only by using evolutionary algorithm when it is taken into consideration under cost function.

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