

Bat Algorithm Based Beamformer for Interference Suppression by Controlling the Complex Weight

Tong Van Luyen and Truong Vu Bang Giang

Abstract—In this study, an adaptive beamformer for pattern nulling of Uniformly Spaced Linear Array (ULA) antennas, which utilized Bat algorithm (BA) to suppress interferences, has been proposed. This pattern nulling has been obtained by controlling the complex weight (both the phase and the amplitude) of each array element. So as to verify the proposal, a number of scenarios of ULA pattern imposed the pre-set nulls have been carried out and compared with those of accelerated particle swarm optimization (APSO). The proposed beamformer has demonstrated the capability to place with precise single, multiple, and broad nulls at arbitrary interference directions, suppress sidelobes, and maintain a predefined beamwidth. Moreover, the beamformer shows faster convergence and higher efficiency regarding null steering in pattern synthesis, as compared with an APSO-based beamformer

Index Terms—Beamformer, BAT algorithm, pattern nulling, interference suppression, ULA antennas.

I. INTRODUCTION

ADAPTIVE beamformers are commonly employed in radar and wireless communication systems for performance improvement through boosting the efficiency of radio spectrum usage, interference suppression, and energy saving. Beamformers are capable of yielding proper weights for smart array antennas to achieve the required pattern [1]. These smart antennas with null-steering capabilities emerge as a promising solution for interference suppression.

A few nulling methods, namely the amplitude-only control, the phase-only control, and the complex weight (including both the amplitude and the phase) control have appeared in numerous studies and implementations [1], [2]. Each of these methods, however, has its own benefits and shortcomings.

Among those, the position-only method [3] is complicated and difficult in terms of accuracy control, because of using mechanical driving system. The amplitude-only control [4], in contrast, is an uncomplicated method as it only adjusts the amplitude excited at each element. In our previous research [5], this control method was adopted, and BA-based beamformer used for adaptive steering nulls of ULA antennas pattern has been proposed and implemented with success. Nonetheless, a drawback of [4], [5] is that the nulling points have been simultaneously and symmetrically put at both sides of the main beam. Phase-only pattern nulling is simpler and

more suitable for the phased arrays, considering the fact that the necessary controls are available without further expense. Furthermore, it is easy to control the main beam direction by adjusting the phase weights [6] - [8]. In our previous work [9], a BA-based beamformer, which is used for ULA antennas pattern nulling using phase-only control method, has been proposed and implemented successfully. However, the problem of phaseonly nulling is inherently nonlinear, and it cannot be solved directly by an analytical method. The nulling equations can only be linear by assuming that the phase perturbations are small [8].

The complex weights method is the most complicated and expensive because for each array element, a controller, a phase shifter, and an attenuator are needed. However, it has been considered the most flexible and efficient one [8], [10] - [12].

Recently, in order to overcome limitations of the classical optimization techniques, which are the issues of getting stuck in local minima in some conditions and inflexibility, various natureinspired optimization algorithms based on computational intelligence approaches have been developed. These algorithms such as genetic algorithm (GA), ant colony optimization, PSO, differential evolution, bee algorithm, and clonal selection have been applied and proved to be better and more flexible than the classical techniques [3] - [7], [13] - [16]. These algorithms have been proposed and implemented with their own benefits and limitations in the array pattern synthesis. Furthermore, for array pattern synthesis, GA and PSO have been widely implemented [2], [13] - [15]. PSO has been proved to be much faster and more efficient than GA [5], [9], [16]. There are many versions of PSO that have been proposed. Among those, in terms of improved convergence speed and simplicity, accelerated particle swarm optimization (APSO) developed by Xin-She Yang has been considered as a good choice [17], [18]. Thus, it has been chosen as a reference.

BA is a novel nature-inspired optimization algorithms rooted in the typical behavior of the bat which uses echolocation for finding prey, dodging obstacles, and identifying their roosts and crevices at night. This method has been applied successfully in order to solve a wide range of engineering problems [17], [19]. It has been proved that BA is better than PSO and GA with regards to convergence, robustness and precision [19]. The first time this algorithm was utilized for adaptive beamforming was in [20]. It was demonstrated in [20] that BA was a potential optimization means for adaptive beamforming regarding computation time. Still, this study was in initial stage, hence, it did not sufficiently analyze the utilization of BA in beamforming.

In this study, a beamformer based on BA is proposed to

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synthesize ULA antennas pattern with arbitrary null-steering capacities. In our proposal, the complex weight (both the phase and the amplitude) of excitation for each array element is the controlling parameter, and the main objective is to synthesize array patterns with nulls imposed on directions of interferences. The proposed beamformer has been verified in five scenarios and compared with an APSO-based one. The results show that the beamformer performs competently with regard to steering the nulls to interference directions, suppressing sidelobe, and more efficiently than those of the APSO-based one.

II. PROBLEM FORMULATION

In our study, an ULA antenna of even number of isotropic elements $2N$ (N is an integer) has been used and shown in Fig. 1. The array elements are positioned along the x -axis and symmetrically around the center of the array. The array factor can be defined as:

$$AF(\theta) = \sum_{n=-N}^N \omega_n e^{jndksin(\theta)} \quad (1)$$

where: $\omega_n = a_n e^{j\delta_n}$, $\{n = (-N, \dots, -2, -1, 1, 2, \dots, N)\}$, is the complex weight of n^{th} array element; $k = \frac{2\pi}{\lambda}$ is the wave number; λ is wave length; d is the distance between adjacent elements.

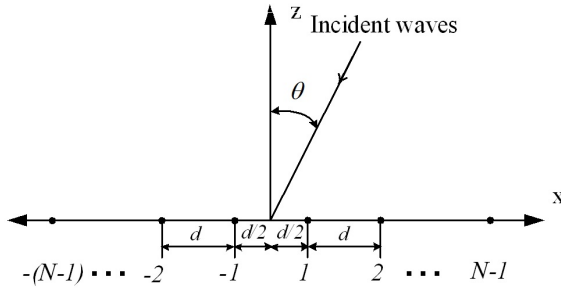


Fig. 1: Geometry of ULA antennas of $2N$ elements

In order to obtain better effectiveness of pattern nulling, the minimum phase perturbation requires odd phase shift [21] ($\delta_n = -\delta_{-n}$). By applying this, anti-symmetrical pattern through the main beam direction ($\theta=0$) is obtained as well. The amplitude has been chosen as even function symmetric in regard to the center of the array. Using the selected odd symmetric phase shift and even symmetric amplitude, the number of weight controllers and attenuators will be reduced by a half.

Since $a_{-n} = a_n$, $\sin(-ndksin(\theta) + \delta_{-n}) = -\sin(ndksin(\theta) + \delta_n)$, and $\cos(-ndksin(\theta) + \delta_{-n}) = \cos(ndksin(\theta) + \delta_n)$, the array factor in (1) can be rewritten as:

$$AF(\theta) = 2 \sum_{n=1}^N a_n \cos(ndksin(\theta) + \delta_n) \quad (2)$$

The objective function F has been built from [5], [9]:

$$F = \begin{cases} 10000 \sum_{i=1}^I [|AF_0(\theta_i)|^2], & \text{for } \theta = \theta_i \quad (3.1) \\ \sum_{\theta=-90^\circ}^{90^\circ} [|AF_0(\theta) - AF_d(\theta)|^2], & \theta \neq \theta_i \quad (3.2) \end{cases} \quad (3)$$

where: (3.1) is for placing the null points, in which I is the maximum number of interferences; (3.2) is used to reduce SLL and to keep the beamwidth within a maximum allowable change; AF_0 and AF_d are the optimized array factor obtained by using an optimization algorithm, which will be BA in this paper, and the desired array factor, respectively; θ_i are the angles of null points.

III. PROPOSAL OF THE BEAMFORMER

A. BAT Algorithm

BAT algorithm (BA) is a novel metaheuristic algorithm for global optimization initiated by Xin-She Yang in 2010 [19]. Its fundamental principal is inspired by the social behaviors of microbats, which is the echolocation behavior of microbats to sense distance.

In BA [17, 19], each bat (i) is defined by its position x_i^t , velocity v_i^t , frequency f_i , loudness A_i^t , and the emission pulse rate r_i^t in a d-dimensional search space. The new solutions x_i^t and velocities v_i^t at time step t are decided by:

$$\begin{aligned} f_i &= f_{min} + (f_{max} - f_{min})\beta \\ v_i^t &= v_i^{t-1} + (x_i^t - x_*)f_i \\ x_i^t &= x_i^{t-1} + v_i^t \end{aligned} \quad (4)$$

where: $\beta \in [0, 1]$ is a random vector drawn from a uniform distribution; x_* is the current global best location (solution) which is specified after comparing all the solutions among all the n bats; Frequency range is defined by f_{min} and f_{max} , which are selected according to the domain size of the problem of concern.

For starters, each bat is randomly assigned a frequency which is drawn uniformly from $[f_{min}, f_{max}]$. As for local search, once a solution is singled out from the current best solutions, a new solution for each bat is created locally employing random walk as:

$$x_{new} = x_{old} + \varepsilon A^t \quad (5)$$

where: $\varepsilon \in [0, 1]$ is a random number; A^t is the average loudness of all the bats at time step t .

Moreover, in consecutive iterations, the A_i and the rate r_i of emission pulse can be renewed by

$$A_i^{t+1} = \alpha A_i^t \quad (6)$$

$$r_i^{t+1} = r_i^0 [1 - \exp(-\gamma t)] \quad (7)$$

in which $0 < \alpha < 1$ and $0 < \gamma$ are constants.

B. Proposed Beamformer

A BA-based beamformer using complex weight control for interference suppression has been developed from [5], [9], [22] and its flowchart is being presented in Fig. 2. Operation of the beamformer is described as follows:

Initializing (I):

- Setting the input data, for example: number of array elements (N), Direction of Arrival (DOA) of Interferences; number of iteration (i); maximum number of iterations (Max_I); and the termination criterion (Threshold).
- Initializing bat population in which parameters of each bat are: location x_i ; velocity v_i ; pulse frequency f_i ; pulse rate r_i ; and loudness A_i . Each bat is in correspondence with a potential solution.

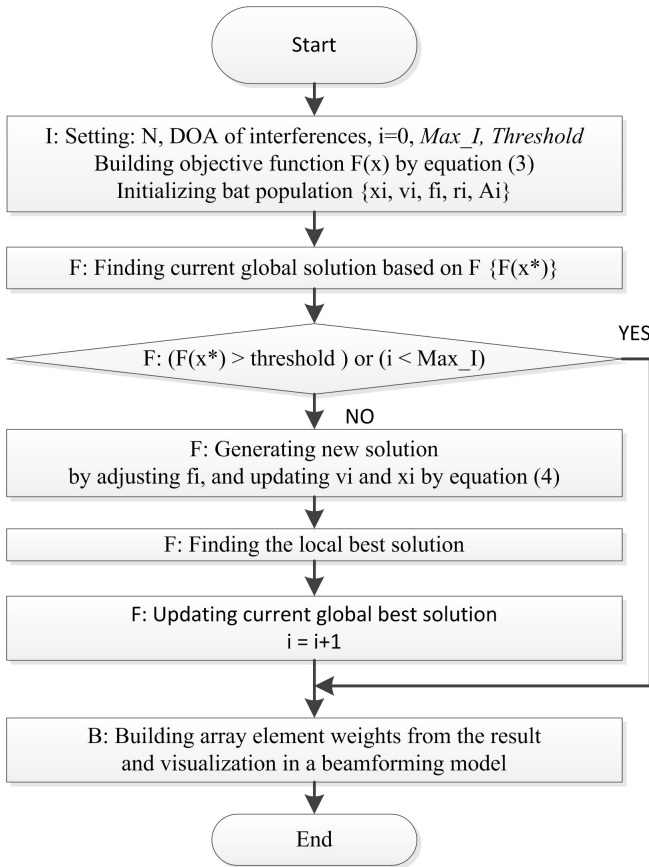


Fig. 2: Flowchart of the proposed beamformer

Finding the best solution (F):

The beamformer consecutively calculates and searches for the current best solution based on the BA. The operation is completed when the termination criterion or maximum number of iterations is satisfied. After that, the final best solution is obtained.

Building array element weights (B):

From the best solution, the beamformer calculates the corresponding complex weight excited at each element of ULA antenna. These weights will be used for ULA pattern nulling.

IV. NUMERICAL RESULTS

To demonstrate the performance of the proposal for pattern nulling, five scenarios will be performed. It is well-known that the Chebyshev array weights distribution produces the optimum pattern in terms of a trade-off between the sidelobe level and the first null beamwidth of main beam for equally spaced arrays [23]. Therefore, in this paper, array factor of Chebyshev array (-30 dB SLL, $\lambda/2$ interelement spacing, and 20 isotropic elements) has been chosen as a desired one to control SLL and beamwidth of the main beam. The step size of theta angle in equation (3) is one degree.

Initial parameters for BA have been chosen for all investigation scenarios as: population size (pop): 500 and number of iterations (ite): 100 (except for the first scenario); step size of random walk is 0.01; boundary frequency values: $f_{min} = 0$ and $f_{max} = 1$. The acceleration parameters of APSO have been chosen as $\alpha = 0.2$ and $\beta = 0.5$ [17], [18].

In [2], Randy L Haupt found that the phase had more effect on the main beam than the amplitude did and adaptive nulling with little perturbation of phase would not result in significant degradation to the main beam. Moreover, the smaller range of variable phase weight is, the faster convergence can be obtained. Therefore, by experimental process for all investigated scenarios of pattern nulling, search value (x_i) has been chosen as: (1) variable phase of weight has been limited in the range of -0.1 to 0.1 radian, and (2) variable amplitude of weight is in the range of 0 to 1.

In order to demonstrate the capability of our proposed beamformer for interference suppression, five scenarios have been constructed. The first scenario is the initial stage to evaluate operation of the proposal beamformer (See IV.A). The second to the fifth scenario are used for the purposes of investigating and comparing the ability of null-steering of the proposal (See IV.B IV.D) with that of the APSO-based beamformer. Consequently, all simulation results presented in the figures are average values of 50 Monte Carlo simulations.

A. Convergence Characteristics

In the first scenario, for starters, the convergence capability of our proposed beamformer, which is used in the case of gaining the desired optimization pattern as Chebyshev array pattern with -30 dB SLL, has been investigated. To achieve that, the initial population has been arbitrarily produced; population size has been selected alternatively as 500, 750, and 1000 with 100 iterations. The results have been presented in Fig. 3. It is clear that the beamformer converges at high speed. The population size is inversely proportional to the number of iterations required. When population size reaches 1000, only 2 iterations are needed to achieve $F < 0.5$ ($F_{dB} < 6dB$).

Furthermore, to illustrate the efficiency of the proposed beamformer, its convergence rate will be compared with the APSO-based one. Their convergence rates with population of 500 and 100 iterations have been assessed for sidelobe suppression and illustrated in Fig. 4. It appears that the BA-based beamformer has a much higher speed of convergence than that of the APSO one.

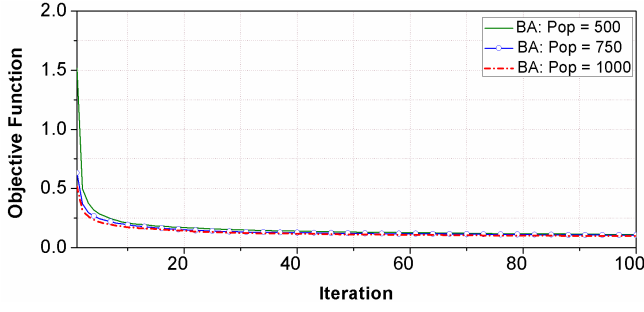


Fig. 3: Objective function of BA with different population sizes.

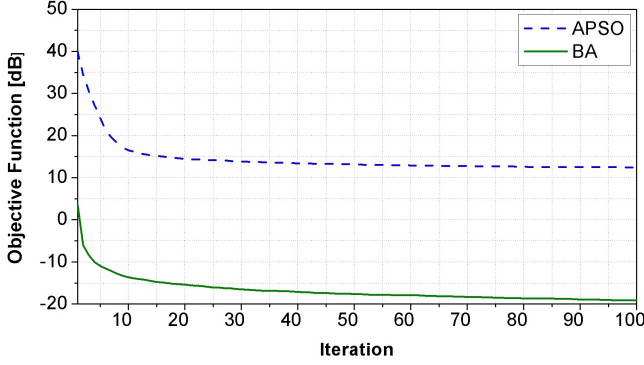


Fig. 4: Objective function between BA and APSO.

B. Pattern with Single Null

The second scenario demonstrates the optimized pattern with single null. The setting of this null can be arbitrary at any angle, which is selected at the peak of the second sidelobe (14°) in this case. The initialization of the population has been done as weights of Chebyshev array with -30 dB SLL. In Fig. 5, optimized patterns with single null achieved by our proposal based on BA and APSO (BA and APSO patterns) are presented, in which population size is 500, and number of iterations is 100. The BA pattern retains most of characteristics of the initial Chebyshev pattern like half power beamwidth ($HPBW = 7, 64^\circ$) and SLL (-30 dB) with the exception of

a few sidelobes with maximum SLL of -27.02 dB and null point at 14° . The null depth level (NDL) is -86.19 dB. In addition, the single null pattern optimized by the BA is better than that of the APSO regarding NDL at the desired null point.

C. Pattern with Multiple Nulls

In the third scenario, the beamformer will be used to separately set multiple nulls at -33° , -26° , -14° , -40° , 20° , and 40° , which correspond to the peaks of six sidelobes next to the main beam of Chebyshev array pattern. As shown in Figs. 6, 7, the patterns with multiple nulls at the predefined locations have been exactly obtained. All the NDLs are deeper than -74 dB, all the SLLs are lower than -24 dB (Fig. 6) or -27 dB (Fig. 7), and HPBW approximately equals to that of Chebyshev pattern. The BA pattern shows advantages over the APSO pattern in terms of NDL.

D. Pattern with Broad Null

In interference suppression application, if the DOA of interferences show minor changes in accordance with time, or are not identified with precision, or a null is constantly steered for gaining a proper signal-to-noise ratio, a broad null is required. In the fourth scenario, the patterns with broad nulls placed at the target sectors of $[-50^\circ, -20^\circ]$ or $[-30^\circ, -20^\circ]$ and $[45^\circ, 60^\circ]$ have been obtained and illustrated in Figs. 8, 9 as a demonstration of the capability of broad interference suppression. It can be observed that a broad null (minimum NDL < -55 dB) on the BA patterns at that target sector has been obtained. The beamwidth stays the same without significant changes, and with maximum SLL of -18 dB. According to the results, BA pattern surpasses the APSO one in terms of NDL.

In all of the above scenarios, the null points of the patterns have been set accurately and the beamwidths have been approximately preserved. Notwithstanding this, SLLs were bigger than -30 dB. To hold maximum SLL at a predefined value (-30 dB) and a broad null at the target sectors of $[-30^\circ, -20^\circ]$ and $[45^\circ, 60^\circ]$ as well, the fifth scenario has been conducted, in which AF_d has been substituted by the array

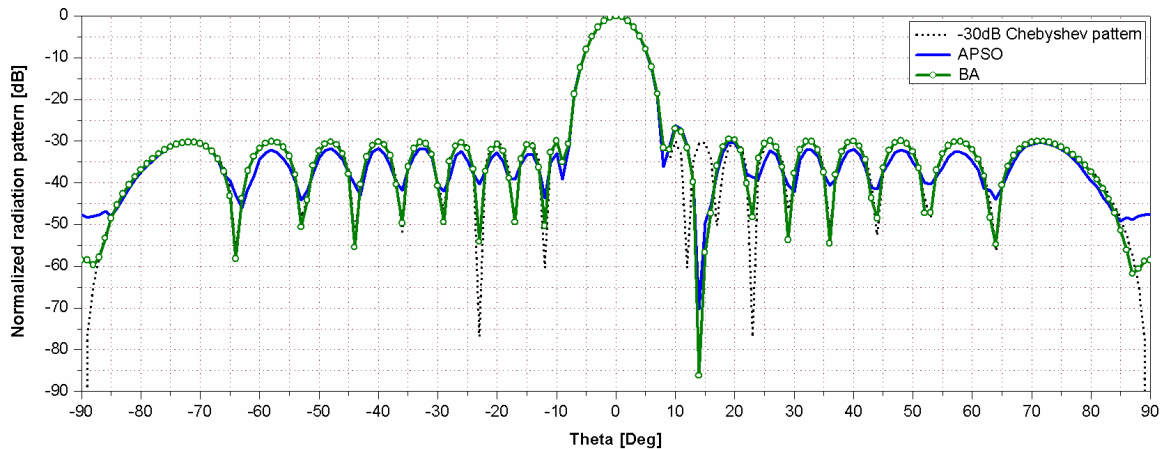


Fig. 5: Optimized patterns with single null at 14° .

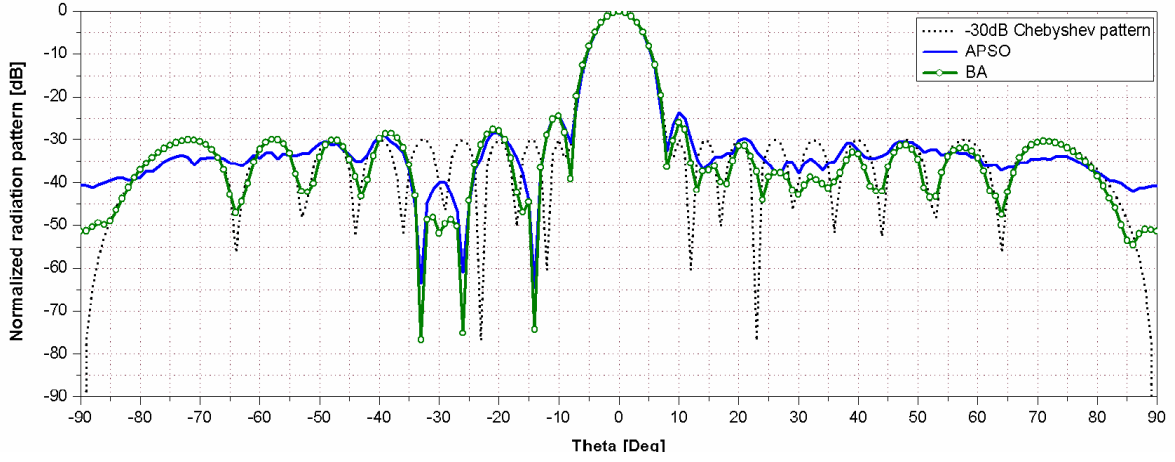


Fig. 6: Optimized pattern with three nulls at -33° , -26° , and -14° .

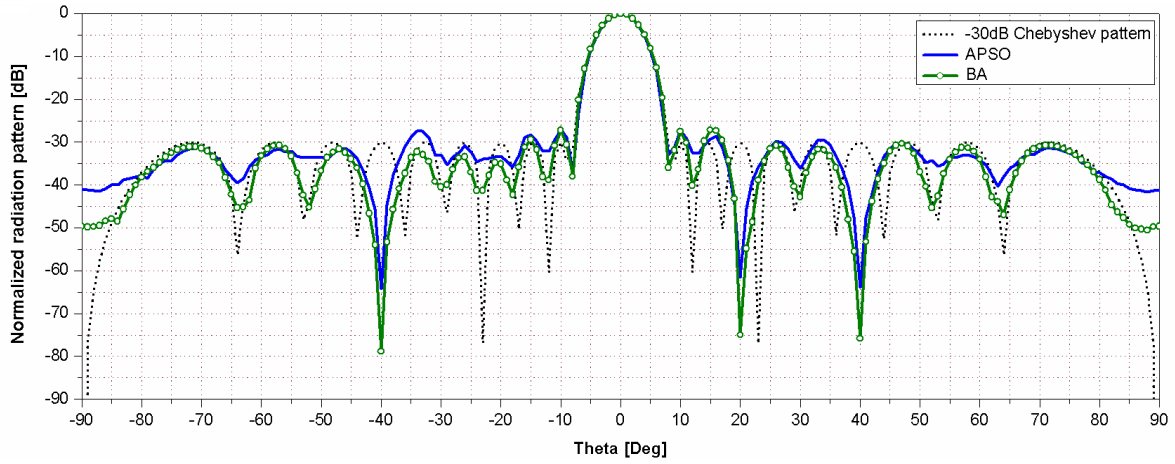


Fig. 7: Optimized pattern with three nulls at -40° , 20° , and 40° .

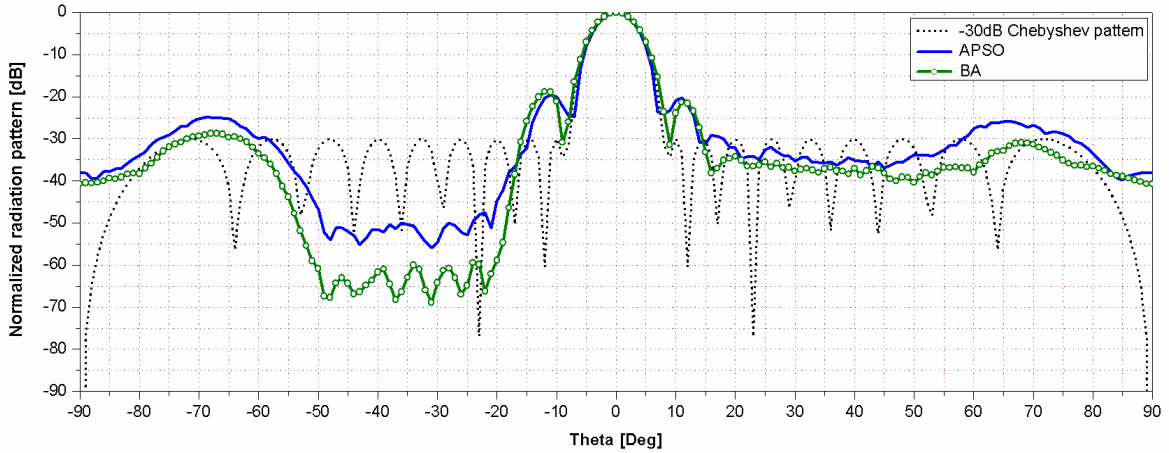


Fig. 8: Optimized pattern with a broad null from -50° to -20° .

factor of Chebyshev array with SLL of -44 dB. Optimized patterns have been shown in Fig. 10. From the result of the simulations, there exists a trade-off between the SLL and the beamwidth of the patterns, which possess maximum SLL of -30 dB and a broadened HPBW. However, the results indicate that BA pattern gives a greater performance in respect of NDL.

As shown in all the scenarios, the SLLs have been reduced to low values however these SLLs is not completely controlled under a predefined value.

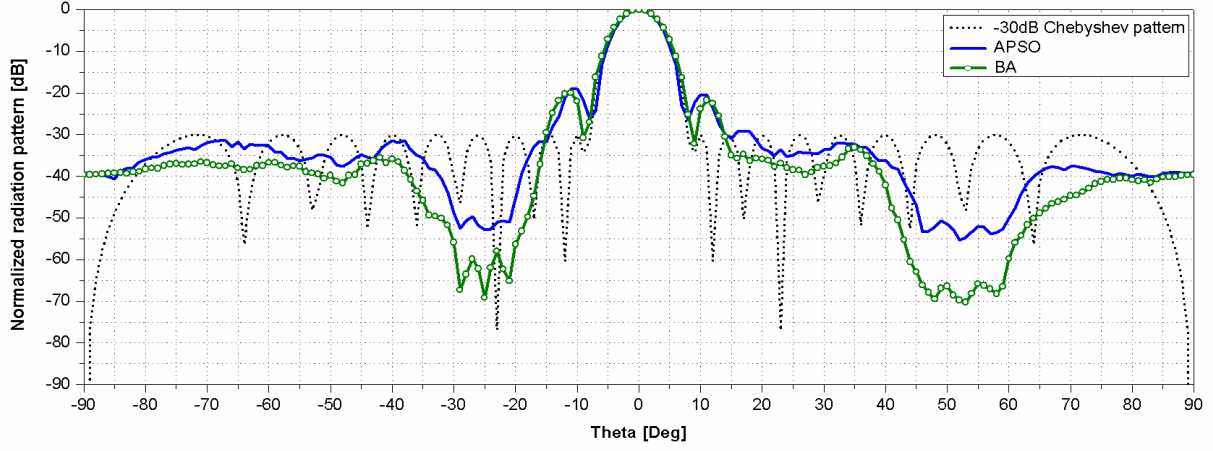


Fig. 9: Optimized pattern with a broad null ($[-30^\circ, -20^\circ]$ and $[45^\circ, 60^\circ]$).

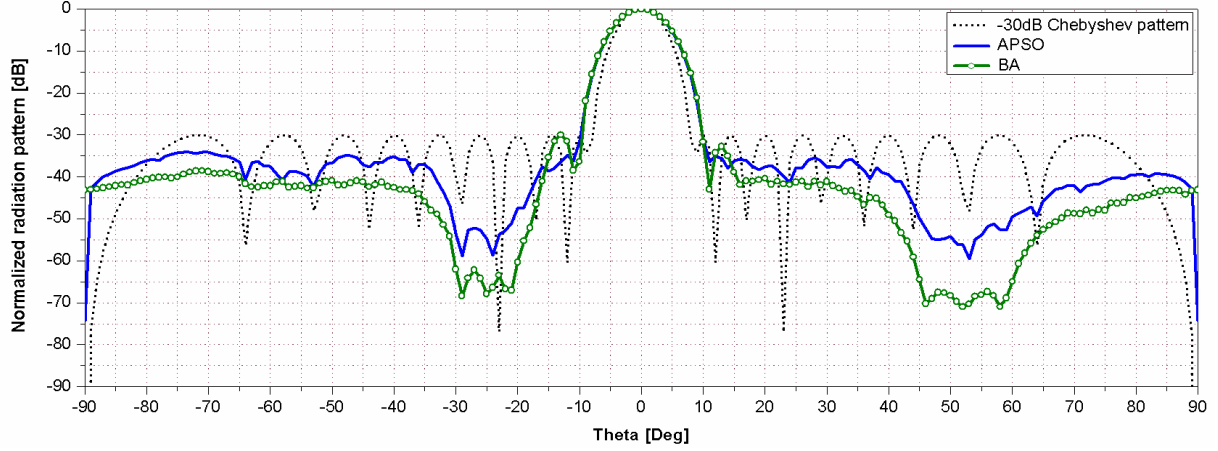


Fig. 10: Optimized pattern with a broad null ($[-30^\circ, -20^\circ]$ and $[45^\circ, 60^\circ]$) and maximum SLL of -30 dB.

V. CONCLUSIONS

In this paper, a BA-based beamformer for ULA antennas pattern nulling, which has utilized complex weight control method, has been proposed and implemented successfully to suppress interferences. The pattern nulling capability of the proposal has been verified by five scenarios consisting of operation speed, pattern nulling with single, multiple and broad nulls. The above mentioned nulls can be imposed accurately to arbitrary interference directions employing our proposed beamformer while the patterns have maintained a predefined HPBW and low SLL. In addition, in comparison with the APSO-based one, our proposal shows higher efficiency as regards computation time and adaptive null steering in array pattern nulling synthesis. In this study, the proposal has been verified in the conditions of isotropic array elements and without mutual coupling. Toward realistic electromagnetic effect in relation with antennas and propagation, the effect of mutual coupling and element patterns will be investigated in further works.

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