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AMPLITUDE-ONLY PATTERN NULLING OF LINEAR ANTENNA ARRAYS WITH THE USE OF BEES ALGORITHM

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Abstract—An efficient method based on bees algorithm (BA) for the pattern synthesis of linear antenna arrays with the prescribed nulls is presented. Nulling of the pattern is achieved by controlling only the amplitude of each array element. Numerical examples of Chebyshev pattern with the single, multiple and broad nulls imposed at the directions of interference are given to show the accuracy and flexibility of the BA.

1. INTRODUCTION

The null steering in antenna radiation pattern of a linear array to reject unwanted interference sources while receiving the desired signal from a chosen direction has received considerable attention in the past and still of great interest [1–23]. The increasing pollution of the electromagnetic environment has prompted the study of array pattern nulling techniques. These techniques are very important in radar, sonar and many communication systems for minimizing degradation in signal-to-noise ratio performance due to undesired interference.

The nulling methods are generally based on controlling the complex weights (both the amplitude and the phase), the amplitude-only, the phase-only, and the position only of the array elements. Interference suppression with complex weights is the most efficient because it has greater degrees of freedom for the solution space [1, 13]. On the other hand, it is also the most expensive considering the cost of both phase shifter and variable attenuator for each array element. Furthermore, when the number of elements in the antenna array increases, the computational time to find the values of element amplitudes and phases will also increase. The amplitude-only control [3, 4, 13, 14, 19, 23] uses a set of variable attenuators to adjust the element amplitudes. If the element amplitudes possess even symmetry about the center of the array, the number of attenuators and the computational time are halved. The problem of phase-only and position-only nulling is inherently nonlinear and it can not be solved directly by analytical methods without any approximation. By assuming that the phase or position perturbations are small, the nulling equations can be linearized. The phase-only control [5, 6, 9, 17, 21, 22] utilizes the phase shifters while the position-only control [7–11, 15] needs a mechanical driving system such as servomotors to move the array elements. Phase-only null synthesizing is less complicated and attractive for the phased arrays since the required controls are available at no extra cost, but it has still common problem.

The classical optimization techniques used for antenna array synthesis are likely to be stuck in local minima if the initial guesses are not reasonably close to the final solution. The most of the classical optimization techniques and analytical approaches also suffer from the lack of producing flexible solutions for a given antenna pattern synthesis problem. The disadvantages of the classical and analytical techniques and rapid development of computer technologies in recent years have encouraged the researcher to use the evolutionary optimization algorithms based on computational intelligence methodologies. It was shown in [4, 6, 8, 9, 12, 14–16, 18–20, 23–32] that the evolutionary optimization techniques such as the genetic algorithm, ant colony optimization, particle swarm optimization, differential evolution and clonal selection are capable of performing the better and more flexible solutions than the classical optimization techniques and the conventional analytical approaches. These techniques have been used with their own benefits and limitations in the antenna array pattern synthesis.

In this paper, an alternative method based on the bees algorithm (BA) [33–36] is presented to steer the single, multiple and broad-band nulls to the directions of interference by controlling only the element amplitudes of linear antenna arrays. The BA is an optimization algorithm inspired by the natural foraging behavior of honey bees to find the optimal solution. To our best knowledge, it is the first attempt to use a method based on the BA in solving the array pattern nulling problem.

The BA proposed by Pham et al. [33–36] was used in this paper as it proved to have a more robust performance than other intelligent optimisation methods for a range of complex problems. The results obtained by Pham et al. [34] for multi-modal functions in n-dimensions show that the BA has remarkable robustness, producing a 100% success rate. The BA converged to the maximum or minimum without becoming trapped at local optima. It was illustrated in [34] that the BA generally outperformed other techniques such as the deterministic simplex method, the stochastic simulated annealing optimization, the genetic algorithm and the ant colony system regarding speed of optimization and accuracy of the results. The BA was successfully used to train the learning vector quantization (LVQ) and the multi-layered perceptron (MLP) neural networks for control chart pattern recognition [33, 36]. Despite the high dimensionality of these problems, the BA succeeded in training more accurate classifiers than those produced by the standard LVQ training algorithm and the backpropagation algorithm. Pham et al. [35] have also presented an application of the BA to the optimisation of neural networks for the identification of defects in wood veneer sheets. It was stated in [34, 35] that the swarm-based optimization algorithms [37–40] with names suggestive of possibly bee-inspired operations do not closely follow the behavior of the bees. In particular, they do not seem to implement the techniques that bees employ when foraging for food.

In this paper, the next section briefly explains the formulation of the problem. The basic principles of the BA are presented in the following section. The numerical examples are then presented and conclusion is made.

2. FORMULATION

If the element amplitudes are symmetrical about the center of the linear array, the far field array factor of this array with an even number of isotropic elements (2N) can be written as

$$F(\theta) = 2\sum_{k=1}^{N} a_k \cos\left(\frac{2\pi}{\lambda} d_k \sin\theta\right) \tag{1}$$

where a_k is the amplitude of the kth element, θ is the angle from broadside, and d_k is the distance between position of the kth element and the array center. In this particular problem of null synthesizing, we restricted ourselves to find an appropriate set of a_k to place array nulls at any prescribed directions. Therefore, the following cost function will be minimized by using BA.

$$C = \sum_{\theta=-90^\circ}^{90^\circ} \left[W(\theta) \left| F_o(\theta) - F_d(\theta) \right| + ESL(\theta) \right] \tag{2}$$

where $F_o(\theta)$ and $F_d(\theta)$ are, respectively, the pattern obtained by using BA and the desired pattern. $W(\theta)$ and $ESL(\theta)$ are included in the cost function to control the null depth level and maximum sidelobe level, respectively. The values of $W(\theta)$ and $ESL(\theta)$ should be selected by experience such that the cost function is capable of guiding potential solutions to obtain satisfactory array pattern performance with desired properties. In the following section, the BA is described briefly.

3. BEES ALGORITHM

3.1. Bees in Nature

A bee colony can be thought of as a distributed creature that can extend itself so as to utilize a large number of food sources at long distances in multiple directions [37, 38]. The colony tries to attain the most optimal use of colony members by employing more bees for visiting flower areas with more nectar and pollen that can be collected with less effort than the areas with less nectar and pollen [39, 40].

The food search process begins by sending the scout bees from the colony to search for and then evaluate potential flower patches around the hive. A certain percentage of the colony is kept as the scout bees and these scout bees continuously and randomly visit the flower patches around the hive during a harvesting season [38].

If these scout bees find a flower patch that has more food than a predetermined threshold, they return to the hive and inform the other members of the colony of their finding by performing a special dance called the "waggle dance" [37]. The waggle dance is shown in Fig. 1. This dance is an essential form of communication between the members of the colony and actually gives three important pieces of information regarding flower areas around the hive. These are the direction, the distance and the quality [37, 40]. This information enables the other members of the colony to accurately evaluate the relative quality of the food resources around the hive and the energy needed to harvest them [40]. After the waggle dance ends, the scout bee goes back to the flower patch with a number of other bees from the colony. The colony

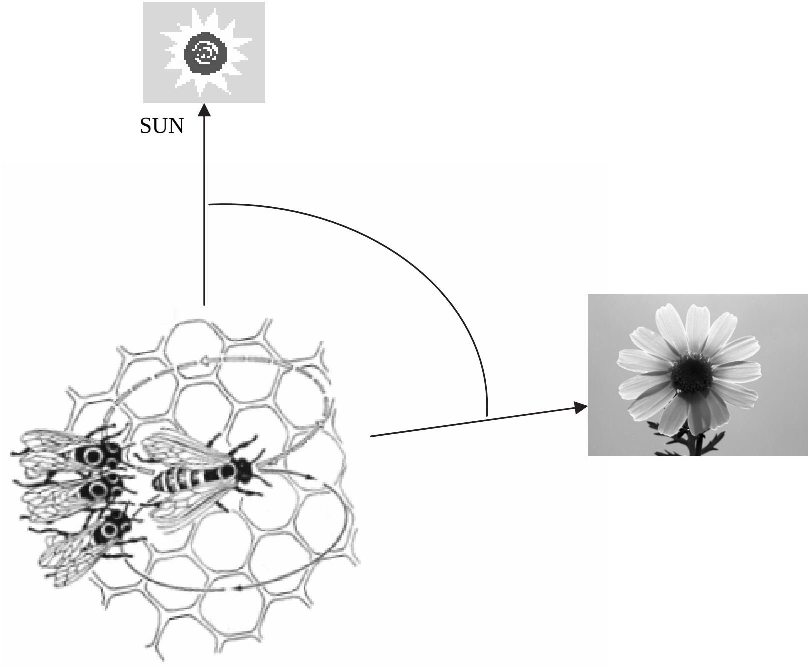

Figure 1. Waggle dance.

determines the number of bees accompanying the scout bee depending on the relative quality of the flower patch. In this way, the colony can harvest food in a rapid and efficient manner.

The bees harvesting a flower patch also monitor its food level. If the food level is still high after harvesting, this is communicated to the colony during the next waggle dance that they perform after returning to their hive, and the colony assigns more bees for next visit to that source [40].

3.2. Bees Algorithm Used in This Work

As summarized in the previous section, the BA is inspired by the behavior of the honey bees to find the optimal solution to a given optimization problem. In this paper, the BA proposed by Pham et al. [33–36] is used for linear antenna array pattern nulling. This algorithm is illustrated in Fig. 2 by using pseudo code.

The BA is controlled by a number of external parameters. These are the number of scout bees (n), number of elite bees (e), number of patches chosen from visited points (m), number of bees employed

```
1. Randomly initialize the population
2. Calculate the fitness of the population
3. While stopping criterion is not satisfied
   // Forming the new population
4. Choose the elite bees and the elite sites for neighborhood search
5. Choose other sites for neighborhood search
6. Assign bees to the selected sites and calculate their fitnesses
7. Choose the fittest bee from each site
8. Recruit remaining bees to search randomly and calculate their fitnesses
9. End While
```

Figure 2. Pseudo code of the basic bees algorithm.

for patches visited by elite bees (nep), number of bees employed for other selected patches (nsp), size of patches (ngh) and the stopping criterion. The algorithm begins optimization by randomly placing the n scout bees to the search space. The fitness values of the points that scout bees visited are determined in step 2.

The bees having the highest fitness values are selected as "elite bees" in step 4. The algorithm then performs several searches around the neighborhoods of the elite bees and of the other bees in steps 5–7. The fitness values may alternatively be used to calculate the probability of selecting the bees. The algorithm employs more bees to follow the elite bees than the other bees in order to perform a more detailed search around the neighborhood of the points visited by the elite bees, which represent more promising solutions. Differential recruitment within scouting is also an important operation of the BA. Both scouting and differential recruitment are utilized in nature.

In step 7, however, only one bee with the highest fitness value will be selected for each site to generate the next bee population while there is no such a restriction in nature. This is necessary here to reduce the number of points to be visited. In order to explore new potential solutions, the remaining bees in the population are randomly assigned around the search space in step 8. These steps are repeated until the stopping criterion is satisfied. The colony will have two parts to its new population at the end of each iteration. The first part will comprise the representatives from each selected patch and second part will comprise other scout bees assigned to perform random searches.

4. NUMERICAL RESULTS

To show the capability and flexibility of the proposed BA for steering single, multiple and broad-band nulls with the imposed directions by controlling the amplitude-only, six examples of a linear array with 20 isotropic elements have been performed. A 30-dB Chebyshev pattern given in Fig. 3 for 20 equispaced elements with $\lambda/2$ interelement spacing is utilized as the initial pattern .

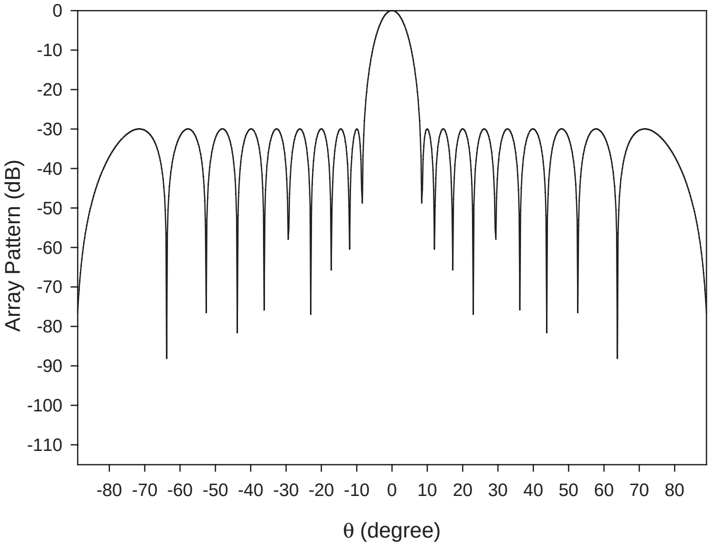

Figure 3. The initial 30-dB Chebyshev pattern.

The following BA parameter values were chosen for the all examples given here: the number of scout bees $n = 500$, number of patches chosen from visited points $m = 10$, number of elite bees $e = 1$, size of patches $ngh = 0.01$, number of bees employed for patches visited by elite bees $nep = 30$, and number of bees employed for other selected patches $nsp = 29$ (initial value). These values were chosen heuristically and verified empirically. The algorithm decreases the value of the parameter nsp starting from 29 to 21 in the optimization process. The simulation results for the all examples are obtained within 2–3 minutes on a personal computer with a Pentium IV processor running at 2400 MHz. This is sufficient to obtain satisfactory patterns with the desired performance on the average.

In the first example, the direction of interference θ_i is chosen at the peak of the second sidelobe, which occurs about 14°. The values of the cost function parameters given in Equation (2) are selected as follows:

$$F_d(\theta) = \begin{cases} 0, & \text{for } \theta = \theta_i \\ \text{Initial pattern}, & \text{elsewhere} \end{cases} \tag{3}$$

$$W(\theta) = \begin{cases} 50, & \text{for } \theta = \theta_i \\ 1, & \text{elsewhere} \end{cases} \tag{4}$$

and

$$ESL(\theta) = \begin{cases} 5, & \text{if } MSL > -28\,\text{dB} \\ 0, & \text{otherwise} \end{cases} \tag{5}$$

where *MSL* given in Equation (5) represents the maximum sidelobe level of achieved pattern in the sidelobe region. The resultant pattern that makes use of the amplitude-only control by the BA is shown in Fig. 4. It is seen from this figure that the pattern preserves the sidelobe and beam width characteristics of the initial Chebyshev pattern with a little disturbance except for the nulling location ($\theta_i = 14°$).

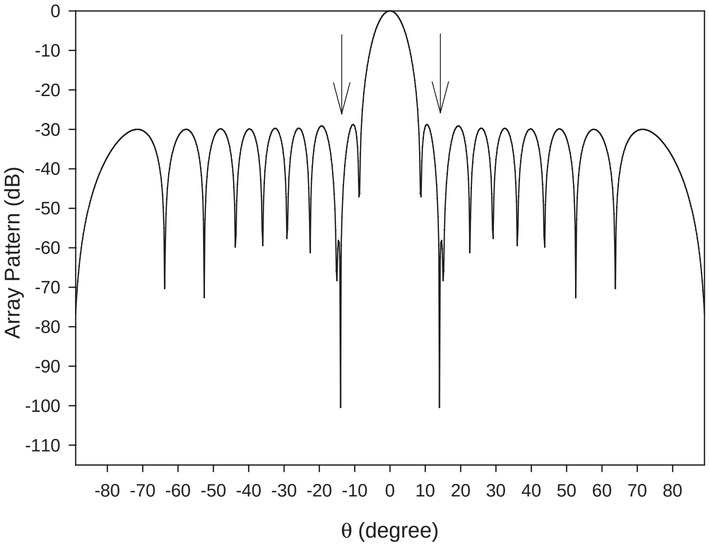

Figure 4. Radiation pattern with one imposed null at 14°.

To inspect the flexibility of the BA, in the second and third examples, the restrictions are made on the maximum sidelobe level and the dynamic range ratio ($|a_{\max}/a_{\min}|$). The restriction on the dynamic range ratio can easily be achieved by suitably setting the search interval of amplitude weights. The patterns with the restricted maximum sidelobe level and dynamic range ratio are shown in Figs. 5 and 6, respectively. It is clear from Figs. 5 and 6 that the BA can

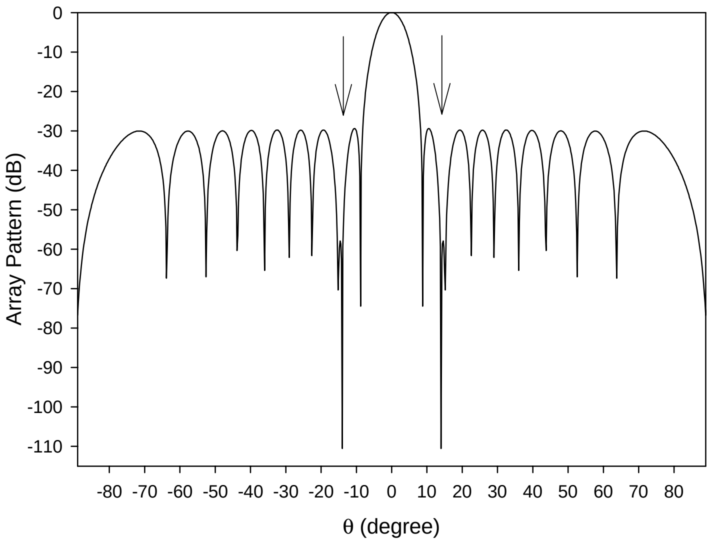

Figure 5. Radiation pattern with the restricted maximum sidelobe level having one imposed null at 14°.

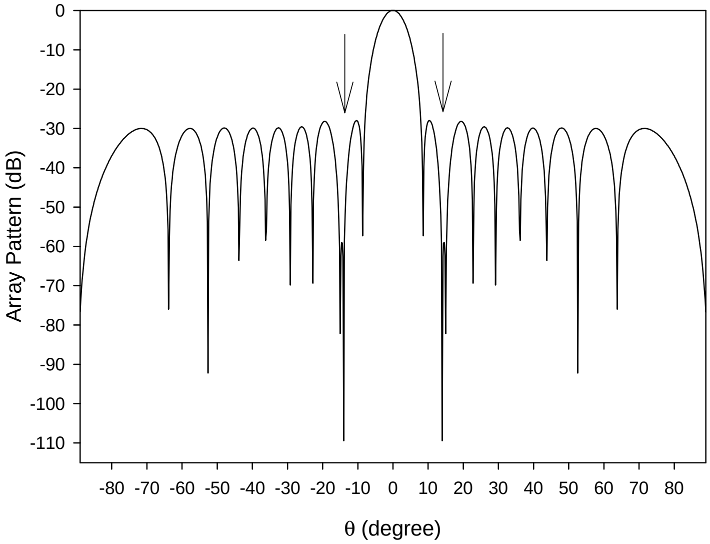

Figure 6. Radiation pattern with the restricted dynamic range ratio having one imposed null at 14°.

obtain the patterns with satisfactory null depth and maximum sidelobe level. The null depth level (NDL), maximum sidelobe level (MSL), and dynamic range ratio (DRR) of the patterns illustrated in Figs. 4–6 are given in Table 1. The results obtained here show that the null depth level, maximum sidelobe level, and dynamic range ratio of the nulling pattern can easily be controlled by using BA.

Table 1. NDL, MSL, and DRR of the patterns in Figs. 4–6.

	Figure 4	Figure 5	Figure 6
NDL (dB)	−100.42	−110.54	−109.50
MSL (dB)	−28.80	−29.42	−28.00
DRR	4.09	4.26	3.85

It is well known that the broad nulls are needed when the direction of arrival of the unwanted interference may vary slightly with time or may not be known exactly, and where a comparatively sharp null would require continuous steering for obtaining a reasonable value for the signal-to-noise ratio. To illustrate the broad-band interference suppression capability of the BA, in the fourth example, the pattern having a broad null located at 30° with $\Delta\theta_i = 5^\circ$ is achieved and is shown in Fig. 7. From the figure, a null depth level deeper than -55 dB is obtained over the spatial region of interest.

In the final two examples, the pattern with two nulls imposed at the peaks of the second and the fourth sidelobes ($\theta_{i1} = 14^\circ$ and $\theta_{i2} = 26^\circ$), and the pattern having triple nulls imposed at the peaks of the second, the fourth and the fifth sidelobes ($\theta_{i1} = 14^\circ$, $\theta_{i2} = 26^\circ$ and $\theta_{i3} = 33^\circ$) are obtained, separately. The patterns with multiple nulls are illustrated in Figs. 8 and 9. It is clear from Figs. 8 and 9 that all the nulls in the imposed directions are deeper than -100 dB.

The element amplitude values calculated by the BA for the patterns given in Figs. 4–9 are listed in Table 2. It is evident from Figs. 4–9 that the patterns are symmetric with respect to the main beam. This is because the symmetry property of the element amplitudes around the array center results in a pattern that is symmetric about the main beam. Therefore, when a null imposed at the one side of the main beam, an image null occurs at the other side of the main beam.

The results shown in Figs. 4–9 confirm that the BA presented in this work can accurately produce the nulling patterns by controlling only the element amplitudes of the linear array. The patterns with the

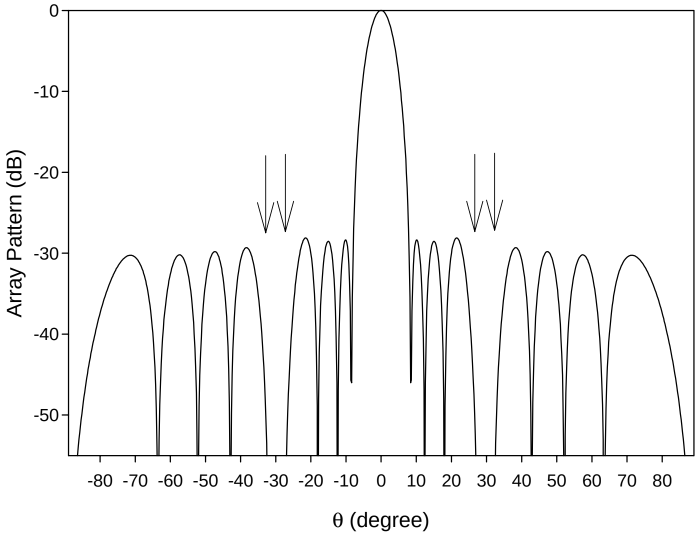

Figure 7. Radiation pattern with a broad null sector centered 30° with $\Delta\theta = 5°$.

Table 2. Element amplitudes normalized according to center elements for Figs. 4–9.

	Initial Chebyshev pattern	Computed with the BA					
k	Figure 3	Figure 4	Figure 5	Figure 6	Figure 7	Figure 8	Figure 9
±1	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
±2	0.97010	0.98927	0.98520	0.99418	0.96710	1.03960	0.99274
±3	0.91243	0.95488	0.94739	0.9669	0.94167	1.01830	0.99116
±4	0.83102	0.88706	0.87701	0.90313	0.86812	0.89955	0.94345
±5	0.73147	0.77968	0.76967	0.79355	0.69680	0.74706	0.76246
±6	0.62034	0.64053	0.63371	0.64974	0.56521	0.63308	0.59229
±7	0.50461	0.48971	0.48303	0.49886	0.55146	0.53022	0.54667
±8	0.39104	0.35057	0.34176	0.36357	0.46650	0.37235	0.42612
±9	0.28558	0.24459	0.23500	0.25960	0.23989	0.21000	0.21265
±10	0.32561	0.31066	0.30307	0.32139	0.25600	0.28035	0.26785

single, multiple and broad nulls imposed at the interference directions are achieved with a good performance. The half power beam width of the nulling patterns is almost equal to that of initial Chebyshev pattern. From the null depth and the maximum sidelobe level points of view, the performances of the patterns are also very good.

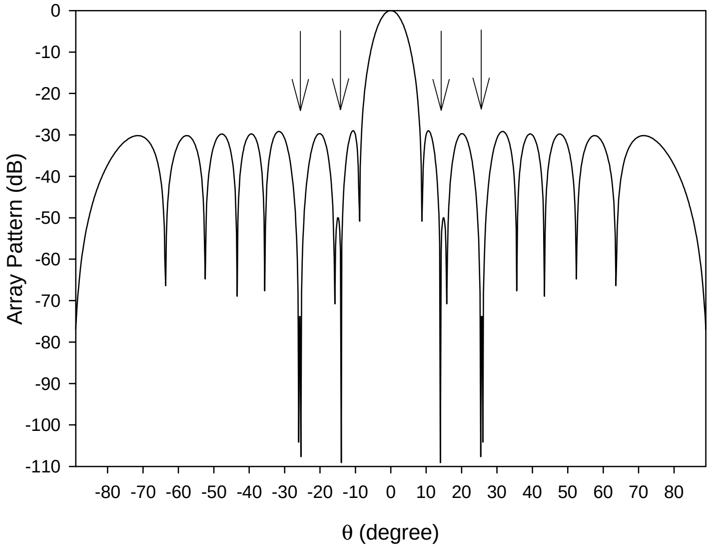

Figure 8. Radiation pattern with double imposed nulls at 14° and 26°.

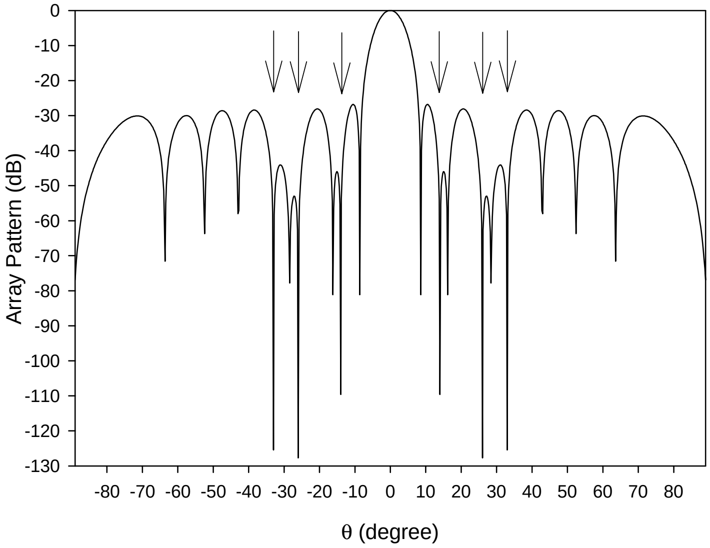

Figure 9. Radiation pattern with triple imposed nulls at 14°, 26°, and 33°.

5. CONCLUSION

In this paper, the BA has been used for interference suppression of a linear antenna array by amplitude-only control. The computer simulation results show that the BA is capable of forming single, multiple and broad band nulls to any prescribed directions by controlling the amplitude of each array element while keeping the pattern as close as possible to Chebyshev initial pattern. The BA can obtain the patterns with satisfactory null depth and maximum side lobe level. Although only linear antenna arrays have been considered here, the BA can easily be implemented for arrays with complex geometries as well as nonisotropic-elements. Since the BA has good accuracy and does not require complicated mathematical functions, it can be very useful to antenna engineers for the pattern synthesis of antenna arrays.

REFERENCES

1. Steyskal, H., R. A. Shore, and R. L. Haupt, "Methods for null control and their effects on the radiation pattern," *IEEE Trans. Antennas Propagat.*, Vol. 34, 404–409, 1986.
2. Er, M. H., "Linear antenna array pattern synthesis with prescribed broad nulls," *IEEE Trans. Antennas Propagat.*, Vol. 38, 1496–1498, 1990.
3. Ibrahim, H. M., "Null steering by real-weight control — a method of decoupling the weights," *IEEE Trans. Antennas Propagat.*, Vol. 39, 1648–1650, 1991.
4. Liao, W. P. and F. L. Chu, "Array pattern synthesis with null steering using genetic algorithms by controlling only the current amplitudes," *Int. J. Electronics*, Vol. 86, 445–457, 1999.
5. Shore, R. A., "Nulling at symmetric pattern location with phase-only weight control," *IEEE Trans. Antennas Propagat.*, Vol. 32, 530–533, 1984.
6. Haupt, R. L., "Phase-only adaptive nulling with a genetic algorithm," *IEEE Trans. Antennas Propagat.*, Vol. 45, 1009–1015, 1997.
7. Ismail, T. H. and M. M. Dawoud, "Null steering in phased arrays by controlling the element positions," *IEEE Trans. Antennas Propagat.*, Vol. 39, 1561–1566, 1991.
8. Tennant, A., M. M. Dawoud, and A. P. Anderson, "Array pattern nulling by element position perturbations using a genetic algorithm," *Electronics Letters*, Vol. 30, 174–176, 1994.

9. Liao, W. P. and F. L. Chu, "Array pattern nulling by phase and position perturbations with the use of the genetic algorithm," *Microwave and Optical Technology Letters*, Vol. 15, 251–256, 1997.
10. Hejres, J. A., "Null steering in phased arrays by controlling the positions of selected elements," *IEEE Trans. Antennas Propagat.*, Vol. 52, 2891–2895, 2004.
11. Abu-Al-Nadi, D. I., T. H. Ismail, and M. J. Mismar, "Interference suppression by element position control of phased arrays using LM algorithm," *Int. J. Electronics*, Vol. 60, 151–158, 2006.
12. Ares, F., J. A. Rodriguez, E. Villanueva, and S. R. Rengarajan, "Genetic algorithms in the design and optimization of antenna array patterns," *IEEE Trans. Antennas Propagat.*, Vol. 47, 506–510, 1999.
13. Guney, K. and A. Akdagli, "Null steering of linear antenna arrays using modified tabu search algorithm," *Progress In Electromagnetics Research*, PIER 33, 167–182, 2001.
14. Karaboga, N., K. Guney, and A. Akdagli, "Null steering of linear antenna arrays by using modified touring ant colony optimization algorithm," *Int. J. RF and Microwave Computer Aided Eng.*, Vol. 12, 375–383, 2002.
15. Akdagli, A., K. Guney, and D. Karaboga, "Pattern nulling of linear antenna arrays by controlling only the element positions with the use of improved touring ant colony optimization algorithm," *J. Electromagnetic Waves and Applications*, Vol. 16, 1423–1441, 2002.
16. Karaboga, D., K. Guney, and A. Akdagli, "Antenna array pattern nulling by controlling both the amplitude and the phase using modified touring ant colony optimisation algorithm," *Int. J. Electronics*, Vol. 91, 241–251, 2004.
17. Akdagli, A. and K. Guney, "Null steering of linear antenna arrays by phase perturbations using modified tabu search algorithm," *J. Communications Technology and Electronics*, Vol. 49, 37–42, 2004.
18. Khodier, M. M. and C. G. Christodoulou, "Linear array geometry synthesis with minimum sidelobe level and null control using particle swarm optimization," *IEEE Trans. Antennas Propagat.*, Vol. 53, 2674–2679, 2005.
19. Yang, S., Y. B. Gan, and A. Qing, "Antenna-array pattern nulling using a differential evolution algorithm," *Int. J. Microwave RF Computer-aided Engineering*, Vol. 14, 57–63, 2004.
20. Chung, Y. C. and R. L. Haupt, "Amplitude and phase adaptive

nulling with a genetic algorithm," *J. Electromagnetic Waves and Applications*, Vol. 14, 631–649, 2000.

21. Mouhamadou, M., P. Vaudon, and M. Rammal, "Smart antenna array patterns synthesis: null steering and multi-user beamforming by phase control," *Progress In Electromagnetics Research*, PIER 60, 95–106, 2006.
22. Mouhamadou, M., P. Armand, P. Vaudon, and M. Rammal, "Interference suppression of the linear antenna arrays controlled by phase with use of SQP algorithm," *Progress In Electromagnetics Research*, PIER 59, 251–265, 2006.
23. Akdagli, A. and K. Guney, "A clonal selection algorithm for null synthesizing of linear antenna arrays by amplitude control," *J. Electromagnetic Waves and Applications*, Vol. 20, 1007–1020, 2006.
24. Akdagli, A., K. Guney, and B. Babayigit, "Clonal selection algorithm for design of reconfigurable antenna array with discrete phase shifters," *J. Electromagnetic Waves and Applications*, Vol. 21, 215–227, 2007.
25. Boeringer, D. W. and D. H. Werner, "Particle swarm optimization versus genetic algorithms for phased array synthesis," *IEEE Trans. Antennas Propagat.*, Vol. 52, 771–779, 2004.
26. Chen, T. B., Y. L. Dong, Y. C. Jiao, and F. S. Zhang, "Synthesis of circular antenna array using crossed particle swarm optimization algorithm," *J. Electromagnetic Waves and Applications*, Vol. 20, 1785–1795, 2006.
27. Lee, K. C. and J. Y. Jhang, "Application of particle swarm algorithm to the optimization of unequally spaced antenna arrays," *J. Electromagnetic Waves and Applications*, Vol. 20, 2001–2012, 2006.
28. Yang, S., Y. B. Gan, and A. Qing, "Sideband suppression in time-modulated linear arrays by the differential evolution algorithm," *IEEE Antennas and Wireless Propagation Lett.*, Vol. 1, 173–175, 2002.
29. Kurup, D. G., M. Himdi, and A. Rydberg, "Synthesis of uniform amplitude unequally spaced antenna arrays using the differential evolution algorithm," *IEEE Trans. Antennas Propagat.*, Vol. 51, 2210–2217, 2003.
30. Mitilineos, S. A., S. C. A. Thomopoulos, and C. N. Capsalis, "Genetic design of dual-band, switched-beam dipole arrays, with elements failure correction, retaining constant excitation coefficients," *J. Electromagnetic Waves and Applications*, Vol. 20, 1925–1942, 2006.

31. Ayestarán, R. G., J. Laviada, and F. Las-Heras, "Synthesis of passive-dipole arrays with a genetic-neural hybrid method," *J. Electromagnetic Waves and Applications*, Vol. 20, 2123–2135, 2006.
32. Mahanti, G. K., A. Chakraborty, and S. Das, "Design of fully digital controlled reconfigurable array antennas with fixed dynamic rage ratio," *J. Electromagnetic Waves and Applications*, Vol. 21, 97–106, 2007.
33. Pham, D.T., S. Otri, A. Ghanbarzadeh, and E. Koc, "Application of the bees algorithm to the training of learning vector quantisation networks for control chart pattern recognition," *Information and Communication Technologies (ICTTA'06)*, Vol. 1, 1624–1629, April 24–28, 2006.
34. Pham, D. T., A. Ghanbarzadeh, E. Koc, S. Otri, S. Rahim, and M. Zaidi, "The bees algorithm — a novel tool for complex optimisation problems," *Proc. 2nd Int Virtual Conf. on Intelligent Production Machines and Systems (IPROMS 2006)*, Oxford, Elsevier, 2006.
35. Pham, D. T., A. J. Soroka, A. Ghanbarzadeh, E. Koc, S. Otri, and M. Packianather, "Optimising neural networks for identification of wood defects using the bees algorithm," *IEEE International Conference on Industrial Informatics*, 1346–1351, Singapore, Aug. 2006.
36. Pham, D. T., E. Koç, A. Ghanbarzadeh, and S. Otri, "Optimisation of the weights of multi-layered perceptrons using the bees algorithm," *5th International Symposium on Intelligent Manufacturing Systems*, 38–46, Sakarya University, Turkey, May 29–31, 2006.
37. Frisch, K. V., *Bees: Their Vision, Chemical Senses and Language*, Revised Edition, Cornell University Press, Ithaca, New York, 1976.
38. Seeley, T. D., *The Wisdom of the Hive: The Social Physiology of Honey Bee Colonies*, Harvard University Press, Cambridge, Massachusetts, 1996.
39. Bonabeau, E., M. Dorigo, and G. Theraulaz, *Swarm Intelligence: from Natural to Artificial Systems*, Oxford University Press, New York, 1999.
40. Camazine, S., J. L. Deneubourg, N. R. Franks, J. Sneyd, G. Theraula, and E. Bonabeau, *Self-Organization in Biological Systems*, Princeton University Press, Princeton, 2003.