Feasibility Study on Beam-Forming Technique With 1-D Mechanical Beam Steering Antenna Using Niching Genetic Algorithm

No-Weon Kang, Changyul Cheon, and Hyun-Kyo Jung

***Abstract*—Recently, mechanical beam steering microstrip patch array antenna is fabricated using MEMS technology, and its pattern is measured by experiment. As one of its applications, the authors propose a new beam-forming method without phase shifters. Based on the radiation pattern of the element antenna, niching genetic algorithm adopting restricted competition selection (RCS) is used for the optimal synthesis of the desired radiation pattern. The proposed method successfully generates the desired beam pattern by controlling the current and angle of the element antenna.**

***Index Terms*—Array signal processing, beam-steering antenna, niching genetic algorithms, optimization.**

I. Introduction

IN WIRELESS communications, there has been an increasing interest in smart antennas due to their high-energy efficiency. Conventionally, phased array antennas have been used to generate the desired beam shape by controlling the magnitude and phase of each element antenna. To control the phase of current, each element requires a phase shifter. The phase shifter usually has a high insertion loss and thus degrades the signal-to-noise ratio (SNR) of the system.

Recent development of the MEMS technology makes it possible to fabricate mechanically tilting antennas with low cost by the batch process [1]. The antenna can tilt the beam direction by rotating the antenna mechanically. As an application of the antenna, we propose a new beam-forming technique by rotating each antenna element adequately instead of controlling the phase. This technique can eliminate the phase shifters from the system so that the system is cheaper and we can obtain more gain and, thus, a better SNR of the system.

In this letter, we describe the feasibility and method of beam forming using a one-dimensaional (1-D) mechanical beam steering linear array antenna system without any phase shifter. Conventionally, most beam shape design has been performed using optimization algorithms that optimize for only single optimal goal-like desired beam pattern by controlling design variables such as amplitudes and phases of current [2], [3]. We adopt the niching genetic algorithm using restricted competition selection (RCS) [4]. This algorithm has been developed to optimize multiple optimal goals. In our case, we select the desired beam pattern such as cosecant or sector beam shape and maximum gain as goals.

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II. Niching Genetic Algorithm

Real world optimization problems often present multiple optima in the feasible domain. In particular, it has been shown that there are several good solutions for problems, such as the design of array antenna [5]–[7] or optimizing array antenna radiation patterns [8]–[11].

Recently, a great deal of a work has been carried out to enable more than one optimum to be found. We call the techniques developed for this purpose multimodal optimization techniques (MOTs). MOTs can be applied to single or multiobjective problems. However, there are several problems in performing multiobjective optimization for a microwave device. At first, because of the different sensitivities of the multiple objectives in the different subdomains of the feasible domain, the solution might not represent the designer's preference, particularly when some utility functions are used. The next problem is that not all of the constraints and manufacturing considerations can be taken into account.

Therefore, we only use the most important criteria in constructing the objective function and apply multimodal optimization techniques that identify the multiple optimal profiles by locating local optima as well as global ones. Possible alternative solutions among multiple optima can then be "post processed" using other criteria. That is, the designer might use other criteria and his experience to select the best-generated solution.

In this letter, the objective of optimization is the synthesis of the desired beam pattern, like cosecant or sector shape. Generally, in the case of beam shape synthesis, there are many solutions that satisfy the designer's purpose. We, therefore, apply niching methods that can identify multiple optimal profiles, and then select one.

Two well-known niching techniques are sharing and crowding. In fitness sharing, the fitness of individuals is reduced if there are many other individuals near them, and so the GA is forced to maintain diversity in the population. But it cannot distinguish local optima that are much closer to each other than the niche radius; in other words, it is assumed that the local optima are approximately evenly spread throughout the search space. Improved crowding, namely deterministic crowding (dc, by introducing competition between children

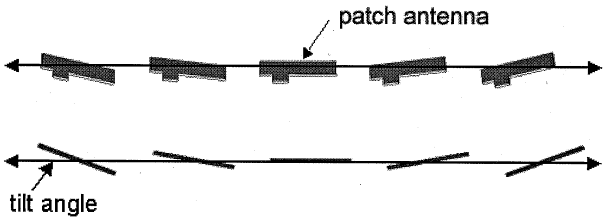

Fig. 1. Mechanical beam steering array antenna.

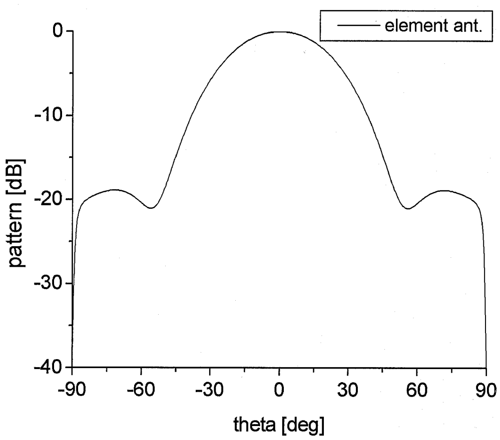

Fig. 2. Radiation pattern of the element antenna ($\xi = 0$).

and parents of identical niches), fails in maintaining certain sought after optima when these recombine to form fitter optima in the search process.

Sharing and dc maintains many individuals in proportion to their fitness. However, in problems such as optimization of microwave devices, an individual with the best fitness is needed per niche because individuals in the same niche have similar shapes, structures, and characteristics. Therefore, a new niching genetic algorithm, known as restricted competition selection (RCS), has been proposed [4].

To reach a stable subpopulation, the RCS restricts competition among dissimilar individuals during selection. As a result of competition among similar individuals, and within the distance between them in search space that is less than a dissimilarity threshold (niche radius), the loser's fitness is changed to zero and the winner's fitness remains unchanged. Therefore, only the best individual per niche can be maintained. Moreover, an elite set is also introduced to preserve the obtained local optima during the generation.

III. Synthesis of Array Antenna Beam Pattern

When the antenna is tilted, the unit antenna's radiation pattern will be shifted to an angle the same as the tilting angle. If we neglect the effect of mutual coupling between antennas and consider each unit antenna's phase difference, we can easily find array pattern by simple superposition of each tilted antenna element's radiation pattern. Basic configuration of 1-D antenna array is shown in Fig. 1, and the radiation pattern of the element when the tilt angle is zero is shown in Fig. 2. With $\exp(jwt)$ time convention, the total radiation pattern $F(\theta)$ is written as (1)

TABLE I
Optimized Current Amplitude and Tilt Angle of Cosecant and Sector Beam Pattern

Antenna No.	Sector		Cosecant	
	I_n [A]	ξ [deg]	I_n [A]	ξ [deg]
1	0.9	39.0	0.5	29.2
2	0.5	-42.3	0.7	-16.3
3	0.9	-42.3	2.1	10.9
4	1.5	32.1	2.5	23.5
5	2.5	-1.7	2.5	29.2
6	1.4	-26.4	1.1	2.9
7	0.5	-22.3	0.5	3.4
8	0.6	-45.3	1.7	2.7
9	0.9	-41.3	0.5	-45.3

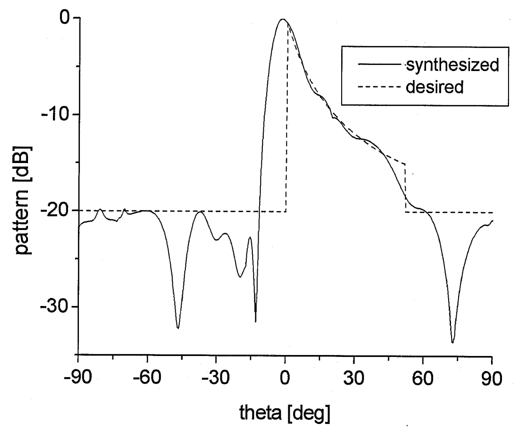

Fig. 3. Synthesized cosecant beam pattern of the mechanical beam steering array antenna.

$$F(\theta) = \sum_{n=1}^{N} I_n e^{j(n-1)kd\cos\theta} f_n(\theta, \xi_n) \tag{1}$$

where ξ_n is the desired tilt angle, I_n is the given current amplitude of nth antenna, and f_n is the radiation pattern of element antenna.

To find optimal current amplitude and tilting angle, we used the RCS GA algorithm. We applied the method presented in this letter to an array of a nine-equispaced unit beam steering array with interelement spacing as 0.5λ. In the case of MEMS fabricated beam steering antenna, the tilt angle cannot vary widely because of the material restriction, so we restrict the tilt angle [$-45°$, $45°$]. We take an objective function as follows

$$objf(\theta) = \sum_{\theta=-\pi/2}^{\theta=\pi/2} |F(\theta) - f_d(\theta)| \tag{2}$$

where $f_d(\theta)$ is the desired radiation pattern, like cosecant or sector pattern. By minimizing the objective function, we can synthesize the desired beam pattern.

After optimization, the RCS GA provides the elite set of each antenna's tilting angle and current amplitude. From this elite set

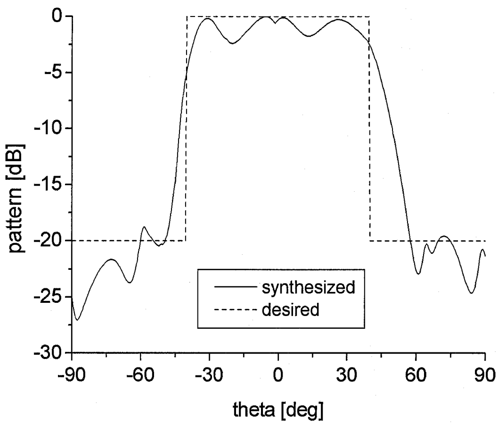

Fig. 4. Synthesized sector beam pattern of the mechanical beam steering array antenna.

we can select the elements that have the appropriate beam shape and maximum gain. The obtained optimized design variables are given in Table I. The maximum to minimum current ratio is about five for both beam patterns. Figs. 3 and 4 show the synthesized cosecant and sector radiation pattern optimized. These figures show that the mechanical beam steering antennas can be used as element antennas of the beam-forming array antenna system without phase shifters.

IV. Conclusion

It is presented that beam forming without phase shifters is feasible by using mechanical beam steering antennas. As an optimal synthesis process of a linear array antenna system to obtain desired beam shape, we newly adopted the RCS GA that could overcome some difficulties in single-search algorithms. Moreover, by the proposed method, the designer's experience, and view and judgment could be reflected effectively.

References

[1] C. W. Baek, S. Song, C. Cheon, Y. K. Kim, and Y. Kwon, "2-D mechanical beam steering antenna fabricated using MEMS technology," in *IEEE MTT-S Dig.*, 2001, pp. 211–214.

[2] O. M. Bucci and G. Mazzarella, "Reconfigurable arrays by phase-only control," *IEEE Trans. Antennas Propagat.*, vol. 49, pp. 919–925, July 1991.

[3] J. S. Kumar, A. Chakraborty, and B. N. Das, "Scanning of cosecant beams generated by a tilted planar array of nonisotropic radiators," *IEEE Trans. Antennas Propagat.*, vol. 39, pp. 919–925, June 1991.

[4] D. H. Cho, H. K. Jung, T. K. Chung, and C. G. Lee, "Design of a short-time rating interior permanent magnet synchronous motor using a niching genetic algorithm," *IEEE Trans. Magn.*, vol. 36, pp. 1936–1940, July 2000.

[5] Z. Altman, R. Mittra, and A. Boag, "New designs of ultra-wide band communication antennas using a genetic algorithm," *IEEE Trans. Antennas Propagat.*, vol. 45, pp. 1494–1501, Oct. 1997.

[6] E. A. Jones and W. T. Joins, "Design of yagi-uda antennas using genetic algorithms," *IEEE Trans. Antennas Propagat.*, vol. 45, pp. 1386–1392, Sept. 1997.

[7] L. Alatan, M. I. Aksun, K. Lelbebicioglu, and T. Biland, "Use of computationally method of moments in the optimization of printed antennas," *IEEE Trans. Antennas Propagat.*, vol. 47, pp. 725–732, Apr. 1999.

[8] K. Yan and I. Lu, "Sidelobe reduction in array-pattern synthesis using genetic algorithm," *IEEE Trans. Antennas Propagat.*, vol. 45, pp. 1117–1122, July 1997.

[9] L. Marcus and L. Vaskelainen, "Optimization of synthesized array excitations using array polynome complex root swapping and genetic algorithms," *Inst. Elect. Eng. Proc. Microwave Antennas Propagat.*, vol. 145, no. 6, pp. 460–464, Dec. 1998.

[10] F. J. Ares-Pena, J. A. Rodriguez-Gonzalez, E. Villanueva-Lopez, and S. R. Pengarajan, "Genetic algorithms in the design and optimization of antenna array patterns," *IEEE Trans. Antennas Propagat.*, vol. 49, pp. 506–510, Mar. 1999.

[11] D. Marcano and F. Duran, "Synthesis of antenna arrays using genetic algorithms," *IEEE Antennas Propagat. Mag.*, vol. 42, June 2000.