Sidelobe Reduction of Low-Profile Array Antenna Using a Genetic Algorithm

Seong Ho Son and Ung Hee Park

ABSTRACT—A low-profile phased array antenna with a low sidelobe was designed and fabricated using a genetic algorithm (GA). The subarray distances were optimized by GA with chromosomes of 78 bits, a population of 100, a crossover probability of 0.9, and a mutation probability of 0.005. The array antenna has 24 subarrays in 14 rows, and is designed as a mobile terminal for Ku-band satellite communication. The sidelobe level was suppressed by 6.5 dB after optimization, compared to the equal spacing between subarrays. The sidelobe level was verified from the far-field pattern measurement by using the fabricated array antenna with optimized distance.

Keywords—Phased array antenna, genetic algorithm, low sidelobe, satellite communication.

I. Introduction

In this letter, we present a new phased array antenna with a low sidelobe pattern for a mobile terminal in Ku-band satellite communication. Because the phased array antenna can steer the direction of the antenna beam without mechanical operation, this antenna is suitable to use under mobile conditions [1].

Because of interference from neighboring satellites, the maximum permissible level of off-axis EIRP density from the terminal antenna in a satellite communication system is strictly regulated by international unions, such as ITU [2]. An array antenna with an equal distance between array elements generally has a high sidelobe due to the grating lobe. To use an array antenna in a satellite communication system, the sidelobe level must be minimized. The pattern of an array antenna with an unequal distance between array elements is better than the pattern of an array antenna with an equal distance between elements, from the sidelobe point of view. The optimum distance between array elements without gain diminution may be determined by various optimization algorithms. The generic algorithm (GA) is one of the algorithms to optimize the system with many design variables. Also, the GA is a parallel, robust, and probabilistic search technique that is simple and easily implemented without gradient calculations, compared to the conventional gradient-based search procedure. The GA can provide the optimum result for a global search and is not easily trapped in local optima [3]. Because of these advantages, the design of the array antenna using GA has been studied during recent years [4]-[6]. Some studies on sidelobe reduction of array antennas have been carried out [7].

Our new mobile array antenna has a low-profile configuration for Ku-band and was designed with a low sidelobe pattern at the transmitting frequency by using a GA.

II. Low Sidelobe Array Antenna Design

1. Fabricated Array Antenna

The fabricated antenna as shown in Fig. 1 is for the mobile applications of Ku-band satellite communication. The receiving (Rx) frequency band is from 11.7 to 12.75 GHz and the transmitting (Tx) frequency band is from 14.0 to 14.5 GHz. The antenna is designed to be lightweight, small, and power efficient. Also, the array antenna has the main feature of low-profile configuration. The planar subarrays inclined to 45 degrees are useful to make a low-profile array antenna with 45 ± 10 degrees

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of beam scanning in elevation. The antenna beam can be steered electronically in elevation and mechanically in azimuth. The Tx radiation pattern of the antenna must have the radiation characteristics required by international regulations [2]. To satisfy this design specification, the array antenna is a good solution.

This array antenna is comprised of 24 subarrays in 14 rows. As shown in Fig. 2, the subarray is a three-layer stacked structure using eight microstrip patches for both Tx and Rx bands. The size of the subarray is 175 mm × 29 mm × 19 mm. The gains of each subarray are close to 17.5 dBi at the center frequencies of the Tx and Rx bands. The total gains of the array antenna are close to 31.3 dBi at the same frequencies. The antenna gain to noise temperature ratio (G/T) and effective isotropic radiated power (EIRP) are 7.1 dB/K and 34.4 dBW, respectively.

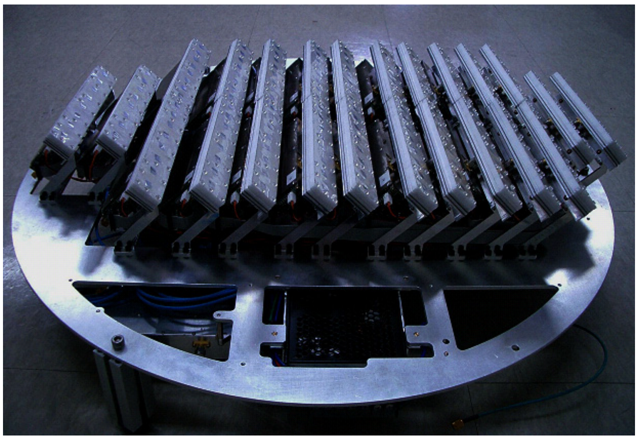


Fig. 1. Fabricated low-profile phased array antenna for Ku-band mobile communication.

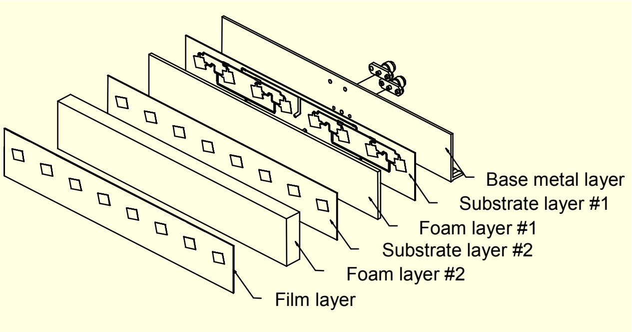


Fig. 2. The configuration of the 8 × 1 subarray.

2. Sidelobe Reduction Method

In this section, the method of optimal subarray distances determination, which is used with the genetic optimization technique, is utilized to achieve the low sidelobe pattern for the proposed structure.

The radiation pattern $E(\theta,\phi)$ of the array antenna can be expressed as in [8]:

$$E(\theta,\phi) = f(\theta,\phi)\sum a_i \exp\{jk\bar{r}_i \cdot \hat{r}\}\,, \tag{1}$$

where $\bar{r}_i = x_i\hat{x} + y_i\hat{y} + z_i\hat{z}$, $\hat{r} = u\hat{x} + v\hat{y} + w\hat{z}$, $u = \sin\theta\cos\phi$, $v = \sin\theta\sin\phi$, and $w = \cos\theta$. Here, $\bar{r}_i$ is the position of the subarray, $\hat{r}$ is the unit directional vector of observation angle θ, ϕ, $f(\theta,\phi)$ is the identical radiation pattern of subarrays, the coefficient a_i is the weighting factor of each subarray, and $k(= 2\pi/\lambda)$ is the wave number.

In the row direction of the subarray, the position of each subarray can be expressed by $r_{i+1}=r_i+d_i$ as shown in Fig. 3. The distance between subarrays is denoted by d_i, which can be defined as

$$d_i = D + \delta_i, \quad (i = 1, 2, \cdots, N-1). \tag{2}$$

Here, D is the default distance between subarrays which is larger than the minimum distance without a shadowing by the front subarray, and δ_i is a perturbed distance which is defined within the range of $\delta_{\min} \le \delta_i \le \delta_{\max}$ and is smaller than D.

Our objective is to find δ_i for all i so that the sidelobe level (*SLL*) is minimized. This optimization problem can be solved by using a GA.

The chromosomes of an individual array antenna are shown in Fig. 3. The distances between subarrays are defined as genes. Genes are perturbed distances expressed with binary numbers in the range of $\delta_{\min} \le \delta_i \le \delta_{\max}$. The GA flow proposed to determine the array distance with low sidelobe pattern is shown in Fig. 4. First, the initial population of chromosomes is randomly generated. A chromosome is a binary string representing all perturbed distances of one array antenna's subarrays. Second, the radiation pattern of each chromosome is calculated, and the maximum sidelobe level is found. Then the fitness of each chromosome is evaluated as

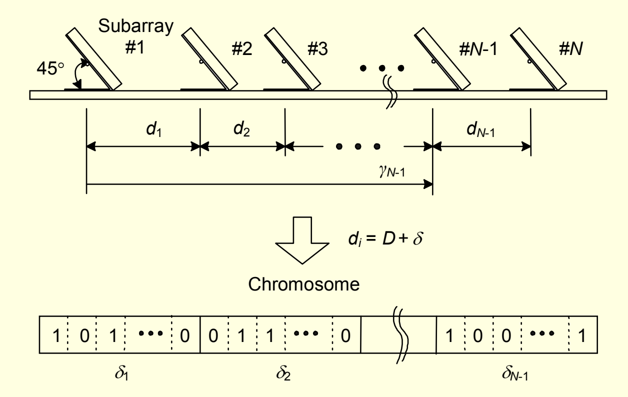


Fig. 3. Chromosome definition of a low-profile array antenna.

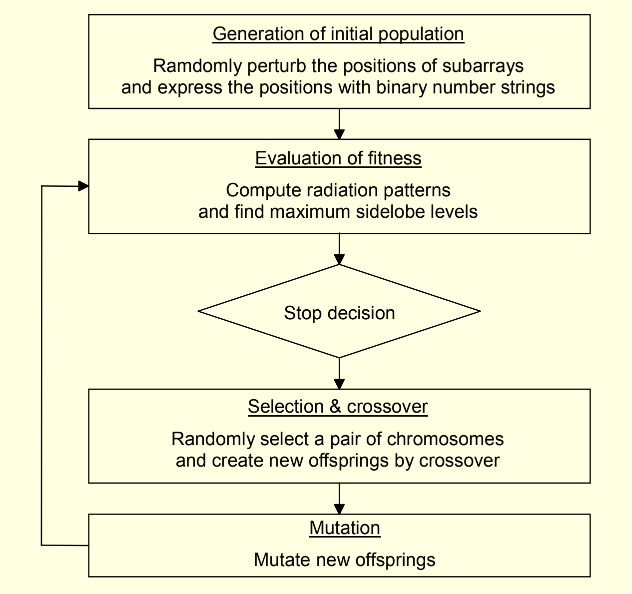


Fig. 4. The GA flow for determining the optimum distances between subarrays.

$$Q = (1-10^{SLL/20})^{\alpha}. \tag{3}$$

Here, Q is the fitness function, SLL the maximum sidelobe level in dB, and α a scaling factor.

It is characteristic of this fitness function that the fitness value is high as the sidelobe level is low. Based on the evaluated fitness value, a pair of chromosomes is selected and mated. The selection rule is based on a roulette wheel and the crossover is achieved at a single random point. Then the mated chromosomes can be mutated according to the mutation probability. In this manner, a new offspring is generated. The iteration is stopped after the evaluation of fitness. Generally, if the current sidelobe level is not improved relative to the prior sidelobe level, the iteration will be terminated. In this way, the optimum spacing between subarrays can be finally determined.

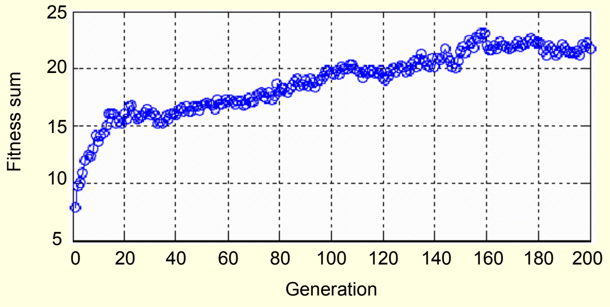
3. Numerical and Experimental Results

The goal size of the array antenna is set within a 555 mm diameter for optimization of subarray spacing; the minimum distance being 33 mm to prevent gain degradation and radiation pattern distortion due to the shadowing of the front subarray.

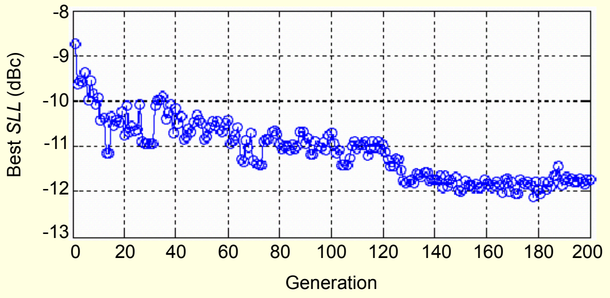
The applied GA parameters are a population size of 100, a chromosome length of 78 bits, and probabilities of crossover and mutation of 0.9 and 0.005, respectively. The scaling factor of fitness is 5. This is summarized in Table 1.

Table 1. Design parameters for GA optimization.

Item	Definition	Value
Subarray row number	N	14
Population size	M	100
Gene size	P (=N–1)	13
Gene bits	Q	6
Chromosome bits	L (=P×Q)	78
Crossover probability	Pc	0.9
Mutation probability	Pm	0.005



(a) Fitness sum

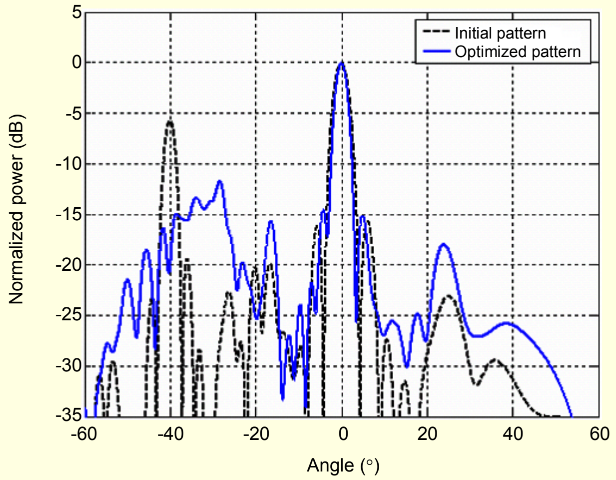


(b) Best sidelobe level

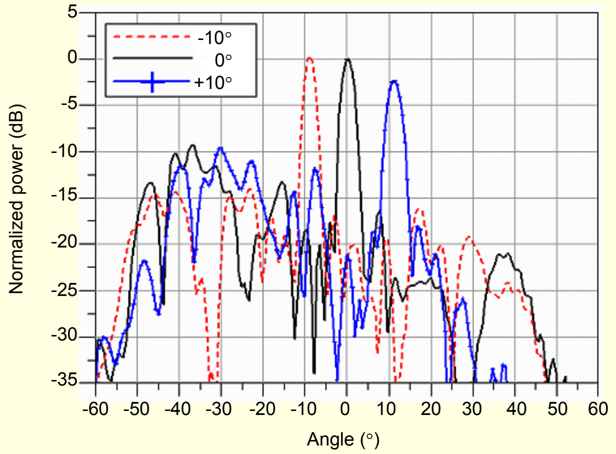
Fig. 5. The optimizing process according to generation.

The spacing between subarrays is perturbed into row direction using the proposed genetic optimization. In Fig. 5, the progressive results of the fitness sum and the sidelobe level are shown. As the generation is propagated, the fitness sum is higher and the best SLL of each generation is progressively lower. Finally, the fitness sum and the best SLL are converged into some values and then the iteration is terminated. The optimal subarray distances from this GA for d_1 to d_{13} are 53 mm, 50 mm, 55 mm, 44 mm, 52 mm, 35 mm, 52 mm, 34 mm, 42 mm, 37 mm, 33 mm, 34 mm, and 34 mm. Figure 1 shows the fabricated low-profile phased array antenna based on this result.

The radiation pattern is shown in Fig. 6, which was simulated and measured at 14.25 GHz in the Tx band. The simulated pattern in Fig. 6(a) shows that the initial sidelobe level is –5.6 dB in the case of an equally-spaced array structure, while the optimized array antenna by GA has a sidelobe of –12.1 dB. The sidelobe of the array antenna was suppressed by 6.5 dB after



(a) Simulated pattern



(b) Measured pattern

Fig. 6. Beam pattern of a low-profile phased array antenna.

optimization. Figure 6(b) shows the measured radiation patterns involving the tilted patterns by phase control of each subarray. The measured pattern for non-tilt is similar to the simulated pattern. The sidelobe level is close to –9.5 dB. If not optimized, the sidelobe level would be worse than this result. In the case of the electronically titled beam into +10 degrees, the gain is degraded due to the shadowing effect of the front subarray; however, the peak value of the sidelobe is almost unchanged.

III. Conclusion

This letter introduced a low-profile phased array antenna for a Ku-band mobile terminal. Equal spacing of subarrays may bring about high sidelobes. This letter proposed a determination method within the limited space of optimum array spacing with a low sidelobe pattern without a change in antenna gain using the genetic optimization technique. The sidelobe level of the developed array antenna was suppressed by 6.5 dB after optimization, compared to an array with equal spacing between subarrays. Also, the optimized subarray spacing was verified from the far-field beam pattern measurement of the fabricated antenna.

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