I. INTRODUCTION

A controlled reception pattern antenna (CRPA) array is widely used for a global positioning system (GPS) in various mobile applications, such as ground vehicles, ships, and aircraft. These applications adopt the CRPA array to suppress interference by forming a pattern null to the direction of an interference source in accordance with array weights iteratively updated by a space–time adaptive processing (STAP) algorithm. Although this iterative process performs well in a stationary system, the process is known to be less functional in a mobile environment because of the fast-varying direction of interference. For this reason, the null steering time has become an emerging consideration in mobile CRPA systems. However, only a few studies have reported on reducing the null steering time by developing a fast adaptive algorithm from a signal processing perspective [1–6].

This paper proposes an optimum array configuration to improve the null steering time for mobile CRPA systems. The proposed array is composed of nine uniformly distributed auxiliary elements with a reference element at the center of the array. The array radius and the vertical positions of the center element are optimized using a genetic algorithm in conjunction with a constrained least-mean-square algorithm. The results demonstrate that the proposed array is suitable for mobile CRPA systems without significant side nulls in satellite directions.

Key Words: Antenna Array, Controlled Reception Pattern Antenna Array, GPS Antenna Array, Interference Mitigation.

Abstract

This paper proposes an optimum array configuration to improve null steering time for mobile controlled reception pattern antenna (CRPA) systems. The proposed array consists of a single reference element at the center and nine auxiliary elements arranged in a circular array. The array radius and the vertical positions of the center element are optimized using a genetic algorithm in conjunction with a constrained least-mean-square algorithm. The results demonstrate that the proposed array is suitable for mobile CRPA systems without significant side nulls in satellite directions.

Optimum Array Configuration to Improve Null Steering Time for Mobile CRPA Systems

Gangil Byun1 · Jong-Chul Hyun2 · Seung Mo Seo3 · Hosung Choo4,*

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rical placement of the center element.

II. PROPOSED ARRAY CONFIGURATION

Fig. 1 presents a flowchart of our optimization process using a genetic algorithm (GA). The process is adopted to determine the optimum array radius and vertical placement of the center element in conjunction with the LMS algorithm for reduced null steering time. The null steering time is defined as the number of iterations to fully mitigate the effect of interference on the LMS algorithm. The process begins with determining an array configuration to compute an array manifold composed of steering vectors for all angles of elevation ($\theta$) and azimuth ($\phi$). The vectors are obtained from the amplitude and phase information of the port currents induced by a plane wave source located at every 1° in both azimuth and elevation directions. Ten satellites are assumed to exist in the upper hemisphere, and a single interference source is incident on the array aperture at an angle of $\theta = 85^\circ$. This angle is chosen because most of the null steering operations are conducted for distant sources, and their incident angles are usually near the azimuth plane ($x$-$y$ plane, $z = 0$). The GPS signal is modulated by binary phase-shift keying at 1.57542 GHz, and its power is assumed to be $-130$ dBm, which is lower than the system noise level of $-110$ dBm, at the array aperture [9]. The interference signal is modeled as a linear chirp with a frequency range of 1.45–1.65 GHz and incident power of $-50$ dBm, which implies that the interference-to-noise ratio is 60 dB. To estimate the null steering time, an adaptive array pattern is computed by iteratively updating array weights using a constrained LMS algorithm [8]. When updating the array weights, a covariance matrix is computed at every iteration using five snapshots. The gain value of the pattern at the interference direction is observed to calculate the gain difference between the previous and the current iterations as shown by the dashed box in Fig. 1. Then, the null steering time is computed when the gain difference between iterations is less than 0.01 dB or when the power of interference is lower than the noise level. In our process, the side-null gain is also taken into account to prevent the blind area from having a gain value of less than $-10$ dBic in the upper array pattern ($\theta \leq 75^\circ$) after the null steering iterations. These cost values are then averaged after conducting several independent simulations for the interference sources located at $\phi = 0^\circ$, $30^\circ$, $\cdots$, and $330^\circ$ as shown in Eq. (1).

$$C_{avg} = \frac{\alpha}{N_\phi} \sum_\phi T_{null}(\phi) + \frac{\beta}{N_\phi} \sum_{\phi, \text{side-null}} \frac{1}{G_{null}(\phi)}, \tag{1}$$

where $T_{null}(\phi)$ indicates the null steering time at each interference direction, and $G_{null}(\phi)$ denotes the side-null gain after the null steering process. The average values of these two metrics are weighted by constant $\alpha$ (0.1) and $\beta$ (0.01), respectively, and summed up to define a convergence criterion of $C_{avg} < 2$ for our optimization process using the GA [10, 11].

Fig. 2(a) illustrates the geometry of a microstrip patch antenna (Amotech Model B25-2D02753-STD70) that is applied to our process as an individual array element [7]. The antenna structure is printed on a ceramic substrate ($\varepsilon_r = 18.25$, $\tan\delta = 0.0035$) with a width of $w_1$ and a thickness of $h_1$. The upper-right corner of the substrate is truncated by $d_1$. The patch has a width of $w_p$, and its feeding position is determined by $f_1$ and $f_2$. Three corners of the patch are truncated by $d_2$, $d_3$, and $d_4$ to achieve circular polarization characteristics. Table 1 presents detailed values of the antenna, which is mounted on a 70-mm square ground to observe its reflection coefficient and radiation patterns using a FEKO EM simulator [12]. The antenna has a reflection coefficient of $-9.1$ dB with an axial ratio of 1.2 dB. The half-power beamwidths of the antenna are $102.9^\circ$ and $103.0^\circ$ in the $xz$- and $yz$-planes, respectively, at 1.57542 GHz.

Fig. 3 shows the proposed array configuration that consists of nine auxiliary elements placed in a circular array and a single reference element at the center. The positions of the auxiliary element are determined by the array radius ($r$) and the angular positions ($\phi_1$, $\phi_2$, $\cdots$, and $\phi_9$). The vertical position of the center element is adjusted by parameter $b$. This vertical placement is important to enhance the resolution of the array pattern at low elevation angles, and it results in better null steering performance ce-

![Fig. 1. Optimization process for reduced null steering time.](image-url)
Fig. 2. Geometry of an array element. (a) Design parameters and (b) radiation patterns.

Table 1. Parameters of the array element

| Parameter | Value (mm) |
|-----------|------------|
| w₁        | 25.0       |
| w₂        | 22.0       |
| d₁        | 2.0        |
| d₂        | 2.0        |
| d₃        | 2.0        |
| f₁        | 8.8        |
| f₂        | 11.0       |
| h₁        | 2.0        |

Table 2. Parameters of the proposed array element

| Parameter | Value |
|-----------|-------|
| Number of antennas | 10 |
| r         | 153.7 mm |
| h         | 55.9 mm |
| ϕ₁        | 0°     |
| ϕ₂        | 40°    |
| ϕ₃        | 80°    |
| ϕ₄        | 120°   |
| ϕ₅        | 160°   |
| ϕ₆        | 200°   |
| ϕ₇        | 240°   |
| ϕ₈        | 280°   |
| ϕ₉        | 320°   |

Fig. 3. Proposed array configuration.

Table 2 presents the optimized values of the proposed array configuration. The array has a large array aperture with an inter-element spacing of about 105 mm, and the center element is placed at h = 55.9 mm above the auxiliary elements. To verify the suitability of this configuration, its null steering performance is compared in the next section with two different arrays that have the same number of elements and the same aperture size.

III. PERFORMANCE EVALUATION

Fig. 4 demonstrates the effectiveness of placing the center reference antenna above the auxiliary antennas using the parameter h. The θ-direction patterns presented in the figure are obtained after the null steering iterations for an interference source located at θ = 85° and ϕ = 150°. The solid line indicates a θ-direction pattern at ϕ = 150° of the proposed array (h = 55.9 mm), and the dotted line shows that of a planar arrangement (h = 0 mm) having the same antenna positions. Although both array configurations form side nulls at around θ = ±30°, the gain reduction can be significantly improved by applying the height difference. For example, the value is improved from −23.8 dBic to −4.6 dBic at θ = 30° for the proposed configuration.

Fig. 5 presents the comparison of gain variations in the direction of interference according to the null steering iterations.
between the proposed array and a 10-element uniform circular array (UCA). The solid line illustrates the variation of array gains in the interference direction for the proposed array configuration, and the dashed line presents the variation of the UCA. We can verify that the null steering time can be more effectively reduced by placing the reference element at the center; for example, the array gain at the interference direction decreases by 15.5 dB compared with the UCA in the seventh iteration. In addition, the proposed array requires only 7 iterations to achieve a null direction gain of –80 dBic, whereas the UCA takes 11 iterations. This improvement becomes more significant in mobile environments, e.g., aircraft and missiles, because these applications require the processing time of less than tens of microseconds.

Another advantage of using the proposed array can be found in Fig. 6, which shows the comparison of the array patterns after interference suppression. The proposed array configuration and the planar array configuration both show a similar trend for the null steering time, but they differ from each other in the side-null gain because of the vertical placement. This analysis indicates that the null steering time is dependent on the array radius. Moreover, it supports the results in Fig. 6, which shows the variations of the side-nulls according to the vertical placement of the center element. To further examine the importance of this vertical placement, the null steering performances are evaluated by adjusting the values of \( h \) from 1 cm to 20 cm at an interval of 1 cm as illustrated in Fig. 8. As the value of \( h \)
We investigated an optimum array configuration to improve the null steering time for CRPA systems. The proposed array was composed of nine auxiliary elements arranged in a circular array and a single reference element, and its design parameters, such as the array radius and the vertical placement, were optimized by the GA. The null steering time and the side-null gain of the optimized array were then calculated in conjunction with the constrained LMS algorithm for evaluation. We verified that the reduced null steering time was suitable for fast interference mitigation and that the side-null gains could be increased by about 37.9 dB with the optimized vertical placement. This finding demonstrates that the proposed array is suitable for use in a mobile environment to achieve fast interference suppression without significant side nulls in satellite directions.

IV. CONCLUSION

We investigated an optimum array configuration to improve the null steering time for CRPA systems. The proposed array was composed of nine auxiliary elements arranged in a circular array and a single reference element, and its design parameters, such as the array radius and the vertical placement, were optimized by the GA. The null steering time and the side-null gain of the optimized array were then calculated in conjunction with the constrained LMS algorithm for evaluation. We verified that the reduced null steering time was suitable for fast interference mitigation and that the side-null gains could be increased by about 37.9 dB with the optimized vertical placement. This finding demonstrates that the proposed array is suitable for use in a mobile environment to achieve fast interference suppression without significant side nulls in satellite directions.

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