The Influence of Signal Incident Angle on Generalized Sidelobe Cancellation System

Shijing Xiao, Fangmin He, Bin Li* and Jin Meng
National Key Laboratory of National Defense Technology for Integrated Ship Power Technology, Naval University of Engineering, Wuhan, Hubei, 430033, China
*Corresponding author’s e-mail: linbin521002@nue.edu.cn

Abstract. Through the simulation modeling of the generalized sidelobe cancellation system, the influence of the interference signal and expected signal at different incident angles on the system is analyzed. The results show that the cancellation ratio is affected by the expected signal, the interference signal and the original beam pattern, and the expected signal loss factor is affected by the angle of incidence of the expected signal. At the same time, the influence of the angle deviation of the interference signal on the system is simulated, and the result shows that the angle deviation of the cancellation ratio is very sensitive to the angle deviation from the beginning to the later.

1. Introduction
With the needs of information warfare, how to effectively suppress interference and enhance the quality of the received signal has always been a hot issue for people to study. The diversified interference situation has also given birth to the development of anti-interference technology. In the anti-jamming technology, there are technical means such as frequency domain spread spectrum and frequency hopping.[1-2] There are anti-jamming technologies that increase the transmission power to achieve the suppression effect. With the application of array signal processing technology, spatial filtering technology with lower power and better anti-jamming effect has emerged. The generalized sidelobe cancellation(GSC) technology is a representative technology of spatial filtering.[3-4] It adaptively adjusts the weighting factor of each array element according to the direction of arrival of the interference signal and the desired signal, so that the direction of arrival of the interference signal forms a recess in the antenna’s directional graph, so as to achieve the purpose of enhancing the desired signal and suppressing interference to improve the signal-to-interference ratio of the system. However, the different incident angles of the desired signal and the interference will cause different anti-interference effects. Based on the generalized side lobe cancellation, this paper simulates the incidence angles of different desired signals and interference signals, and illustrates the influence of the anti-interference system through interference cancellation and communication signal loss factors.

2. Generalized side lobe cancellation mathematical model
In the generalized sidelobe cancellation technology, the most common linear constraint minimum variance criterion (LCMV)[5-6], its specific principle is shown in Figure 1.
The LCMV criterion can be expressed as:

$$w = \arg \min_{w} w^H R w$$

subject to $C^H w = f$.

Among them, $R$ is the autocorrelation matrix of the received signal, $C$ is the $M \times (J+1)$ dimensional constraint matrix, $f$ is the $(J+1)$ dimensional constraint vector, $M$ is the number of antennas in the array, and $J$ is the number of interferences. Then the optimal solution of the above formula is:

$$w_a = (B^H RB)^{-1} B^H Rw_q$$

$$w_q = (CC^H)^{-1} Cf$$

$$w = w_q - Bw_a$$

Where $B$ is the dimensional blocking matrix. Its function is to block the desired signal so that it does not enter the auxiliary branch, and then superimpose the non-adaptive branch with the adjustment of the adaptive weight to obtain the processed signal.\(^{[7]}\)

### 3. Simulation and conclusion

In this section, in the case of an array of 8 elements with a half-wavelength array element spacing, and a snapshot number of 200, the 1GHz amplitude modulation signal is used as the interference signal and the desired signal for simulation.

#### 3.1. System performance index

1. **System cancellation ratio**

   $$K = 10 \log \left( \frac{S/I}_{\text{out}} \right) / \left( S/I \right)_{\text{in}}$$

   $K$ is used to express the system's interference cancellation effect in decibels, which means the system's cancellation performance. $(S/I)_{\text{out}}$ represents the signal-to-interference ratio of the output, and $(S/I)_{\text{in}}$ represents the signal-to-interference ratio of the input.

2. **Expected signal energy loss factor**

   $$\lambda = \frac{|E_p - E_a|}{E_p}$$

   $\lambda$ is used to represent the relative energy lost or added to the desired signal through spatial filtering. This factor can be used to represent the magnitude of the signal energy of the input device and explain the impact of the cancellation system on the original system. Where $E_p$ represents the energy of the expected signal before adaptive filtering, and $E_a$ represents the energy of the expected signal after adaptive filtering.
3.2. The impact of the incident angle of the expected signal and interference signal on the system performance

In the simulation, the incident angle of the desired signal is -20°, and the influence of the incident angle of different interference on the system is shown in Table 1. The beam diagrams before and after cancellation of partial angles are shown in Figure 2. In addition, the angle of the interference signal is fixed at -20°, and the impact of the incident angle of different desired signals on the system is shown in Table 2. The beam diagrams before and after cancellation of partial angles are shown in Figure 3.

| Incident angle/degree | -60 | -19 | -15 | -10 | 0   | 10  | 19  | 60  |
|-----------------------|-----|-----|-----|-----|-----|-----|-----|-----|
| \( K \)               | 19.3136 | 7.3338 | 19.9150 | 11.2186 | 35.4671 | 13.1246 | 16.6039 | 20.6728 |
| \( \lambda \)          | 2.1409   | 2.1386   | 2.1398   | 2.1389   | 2.1395   | 2.1398   | 2.1387   | 2.1389   |

| Incident angle/degree | -60 | -19 | -15 | -10 | 0   | 10  | 19  | 60  |
|-----------------------|-----|-----|-----|-----|-----|-----|-----|-----|
| \( K \)               | 10.2786 | 6.1694 | 6.0438 | 7.5521 | 1.3265 | 8.1242 | 13.9684 | 11.6396 |
| \( \lambda \)          | 0.6920   | 2.3554   | -0.5990   | 1.0574   | -0.8693   | 1.0563   | 2.3569   | 0.6921   |

![Figure 2 Part of the interference signal before and after different cancellation beam diagrams](image-url)
Combining the original beam pattern and the two tables in the simulation results, the following conclusions can be drawn:

① The energy loss of the communication signal mainly depends on the incident angle of the communication signal. When the incident angle is close to the peak of the original beam pattern, the energy increase of the communication signal is small, and even attenuation occurs. When the communication signal is incident from 0°, it is from 0°. The original beam is incident at the maximum point, and the attenuation energy is large, close to 90%.

② The magnitude of the cancellation ratio mainly depends on two factors. The first is that the incident angle of the interference signal is fixed, and the interference cancellation of the communication signal from the wave crest close to the beam pattern is relatively small. The cancellation of the incident interference from the trough close to the beam pattern is relatively large. If the incident angle of the communication signal is fixed, it is contrary to the above conclusion; secondly, when the incident angle of the interference signal and the communication signal are close, they will affect each other, resulting in a smaller signal-to-noise ratio; the farther away from the incident angle of the interference signal, the influence will be affected. The higher the value, the better the cancellation performance.

3.3. The accuracy of the incident angle of interference affects the system
In the GSC system, usually the direction of arrival of the desired signal is known, and the judgment of the interference signal will have a certain error. This section simulates the change of the system cancellation ratio when the interference angle is different from the actual angle. In order to reduce the influence of the original beam on the system, it is assumed that the actual incident angle of the interference signal is 0°, and the simulation results are shown in Table 3.

| Absolute value of angle error/degree | 0     | 0.3   | 0.7   | 1.1   | 1.6   | 2.0   |
|-------------------------------------|-------|-------|-------|-------|-------|-------|
| $K$                                 | 35.4671 | 29.0285 | 26.4802 | 19.3989 | 14.5646 | 6.8687 |
Observing the above table, we can see that when the incident angle of the interference signal is judged without error, it has a very high cancellation ratio. When the error angle increases slightly, the cancellation ratio drops sharply. Later, as the error angle increases, the downward trend of the cancellation ratio weakens, when the overall trend is downward.

4. Conclusion
This article demonstrates that GSC has a good anti-interference effect through modeling and simulation of the GSC system. The simulation analysis of different interference signal incidence angles shows that when the interference signal is incident from the trough of the original beam, the cancellation obtained is relatively small. If the interference signal is incident from the peak, the system cancellation is relatively high, and the expected signal is the opposite. When the angle of incidence of the two signals differs slightly, the performance of the cancellation system will be affected. For the deviation of the incident angle of the interference signal, when the deviation is small, the cancellation ratio decreases significantly compared with the absence of deviation. Then, as the deviation increases, the cancellation ratio still decreases, but the downward trend becomes slower. The loss of the desired signal is mainly reflected in the incident angle of the desired signal. This article provides a certain basis for the development of GSC anti-jamming equipment, and provides a certain reference for how to obtain a higher cancellation ratio for the array antenna.

References
[1] Ziliang Du, Yingmin Wang. 2020, Military wireless communication interference and anti-jamming technology analysis [J]. Radar and Countermeasures, 40(04): 29-32.
[2] Han Xiong. 2021, Filtering Differences and Explanation of Far-Field Spatial Filters [J]. Journal of Russian Laser Research, 42(Prepub) : 181-189.
[3] Zhiyong Li, Hao Lou, Wenting Han, Yuan Zhou. 2021, Radar-communication integrated planar array antenna sharing design [J/OL]. Signal processing: 1-9.
[4] Zhengwei Lei, Xiaoli Wang, Xinwei Ji. 2020, Analysis of anti-jamming design requirements of modern radar systems [J]. Modern Radar, 42(02): 85-90.
[5] Tian Hong. 2021, Design of an Adaptive Sidelobe Cancellation Algorithm for Radar [J]. Journal of Physics: Conference Series, 1754(1) : 012217-.
[6] Chao Long, Qingning Zeng, Ying Luo. 2020, Small array speech enhancement based on noise cancellation and beamforming [J]. Computer Applications, 40(08): 2386-2391.
[7] Ziang Chen, Jiawei Yang, Chenchen Tao. 2021, Adaptive monopulse of GSC structure phased array under main lobe interference [J/OL]. System Engineering and Electronic Technology: 1-9