

# Improved algorithm of multi-mainlobe interference suppression under uncorrelated and coherent conditions

CAI Miaohong, CHENG Qiang, MENG Jinli, ZHAO Dehua

(Nanjing Research Institute of Electronics Technology, Nanjing 210039, China; National Key Laboratory of Radar Detection and Sensing, Nanjing 210039, China; Jiangsu Provincial Key Laboratory of Detection and Sensing Technology, Nanjing 210039, China)

**Abstract:** A new method based on the iterative adaptive algorithm (IAA) and blocking matrix preprocessing (BMP) is proposed to study the suppression of multi-mainlobe interference. The algorithm is applied to precisely estimate the spatial spectrum and the directions of arrival (DOA) of interferences to overcome the drawbacks associated with conventional adaptive beamforming (ABF) methods. The mainlobe interferences are identified by calculating the correlation coefficients between direction steering vectors (SVs) and rejected by the BMP pretreatment. Then, IAA is subsequently employed to reconstruct a sidelobe interference-plus-noise covariance matrix for the preferable ABF and residual interference suppression. Simulation results demonstrate the excellence of the proposed method over normal methods based on BMP and eigen-projection matrix preprocessing (EMP) under both uncorrelated and coherent circumstances.

**Key words:** mainlobe interference suppression; adaptive beamforming; spatial spectral estimation; iterative adaptive algorithm; blocking matrix preprocessing

DOI:10.3969/j.issn.1003-7985.2025.01.011

Modern array radar systems must perform effectively in complex electronic countermeasure environment<sup>[1]</sup>. Sidelobe interferences can be well suppressed by using adaptive beamforming (ABF), sidelobe cancellation<sup>[2]</sup>, and other conventional electronic counter-countermeasures<sup>[3-4]</sup>. However, when the interferences fall into the mainlobe area, the conventional measures may lead to pattern distortion and great loss of the signal of interest (SOI), which may severely influence the angle measurement and effective detection of targets. Therefore, mainlobe interference suppression is a big challenge in radar applications.

Received 2023-12-08, Revised 2024-09-02.

**Biography:** Cai Miaohong (1983—), female, doctor, senior engineer, caimiaohong@cetc.com.cn.

**Foundation item:** The National Natural Science Foundation of China (No. U19B2031).

**Citation:** CAI Miaohong, CHENG Qiang, MENG Jinli, et al. Improved algorithm of multi-mainlobe interference suppression under uncorrelated and coherent conditions[J]. Journal of Southeast University (English Edition), 2025, 41 (1): 84-90. DOI: 10.3969/j.issn.1003-7985.2025.01.011.

To overcome this problem, different techniques have been explored to separate the SOI from mainlobe interferences in space, time, frequency, polarization, or joint domains. In Refs. [5-6], the adaptive beamforming in the range (time) dimension or range-angle (time-space) joint dimensions based on frequency diversity array-multiple input multiple output (FDA-MIMO) radar is adopted to suppress the mainlobe deceptive jamming. However, this type of method requires prior knowledge of the true target location, which is difficult to meet in practical applications. In Refs. [7-8], the adaptive beamforming in the space-polarization joint domains based on distributed polarization radar is suggested, which discriminates mainlobe jamming by constructing the space-polarization steering vector and covariance matrix. The shortcoming of this type of method is the huge system complexity and high cost. As for the space domain, the main methods that have been presented to avoid the drawbacks of conventional ABF can be divided into two categories: (1) auxiliary array methods<sup>[9-10]</sup> and (2) methods based on eigen-projection matrix preprocessing (EMP)<sup>[11-17]</sup> or blocking matrix preprocessing (BMP)<sup>[17-20]</sup>. The auxiliary array methods suffer from great system complexity and high cost, which limit their practical applications. In Refs. [11-12], the EMP method is presented to suppress mainlobe interference by eigen-projection. This method can effectively decrease the main beam distortion, but it still suffers from main beam deviation and high sidelobe<sup>[13]</sup>. Yang et al.<sup>[14]</sup> proposed the EMP-CMR method to achieve mainlobe conformal by using a covariance matrix reconstruction (CMR) technique, but it suffers from shallower sidelobe zero nulls and the degradation of output signal-to-interference-plus-noise ratio (SINR) performance in the case of strong mainlobe interference. Wang et al.<sup>[15]</sup> suggest the IAA (iterative adaptive algorithm)-EMP-CMR method to suppress mainlobe interference, which promotes the array pattern and the output SINR performance for coherent environments in the case that only one mainlobe interference exists along with multiple sidelobe interferences. However, when there are multiple mainlobe interferences, the performances of the EMP-based methods deteriorate dramatically<sup>[16]</sup>. Meanwhile, BMP-based

methods<sup>[17-20]</sup> have been widely applied in recent years. Despite the reduced degrees of freedom, the BMP methods do not change the direction steering vectors (SVs) of sources and are suitable for different interference environments. However, applying BMP requires an accurate DOA estimation of interferences<sup>[21-23]</sup>. Previous studies mainly utilized the Capon<sup>[24-25]</sup> or multiple signal classification (MUSIC)<sup>[26-27]</sup> algorithm for the spatial spectral estimation and DOA estimation of signal sources. Stoica et al.<sup>[28]</sup> and Yardibi et al.<sup>[29]</sup> introduced IAA, which can provide high power estimation performance in a limited number of snapshots for uncorrelated and coherent signal sources.

In this paper, a new IAA-BMP-SINCM approach is presented for suppressing multiple mainlobe interferences. The proposed method discriminates mainlobe interferences via the refined DOA estimation by IAA and the correlation coefficient calculation of direction SVs and rejects the mainlobe interferences via BMP pretreatment. To suppress the residual interferences, the proposed method reconstructs the SINCM by applying IAA again and achieving the preferable ABF that exhibits better array patterns and output SINR performance.

The remainder of this paper is organized as follows. First, the array signal model and the principle of ABF is analyzed. Secondly, the proposed approach for the multi-mainlobe interference suppression method based on IAA, BMP, and SINCM methods is presented. Finally, the simulation results are displayed to verify the effectiveness of the proposed algorithm is shared.

## 1 Signal Model

Consider a received uniform linear array (ULA) with  $M$  omnidirectional antenna elements spaced half a wavelength. The ULA receives waves emitted by  $P + Q + 1$  far-field narrowband sources, including one desired signal,  $P$  mainlobe interferences, and  $Q$  sidelobe interferences. The array receiving snapshot data can be expressed as follows:

$$\mathbf{x} = \mathbf{x}_s + \mathbf{x}_{\text{int}} + \mathbf{n} = \mathbf{a}(\theta_0)s_0 + \sum_{p=1}^{P+Q} \mathbf{a}(\theta_p)s_p + \mathbf{n} = \sum_{p=0}^{P+Q} \mathbf{a}(\theta_p)s_p + \mathbf{n} \quad (1)$$

where  $\{s_p\}_{p=0}^{P+Q}$  denotes the source waveform vectors from imping angles  $\{\theta_p\}_{p=0}^{P+Q}$ ,  $\{\mathbf{a}(\theta_p)\}_{p=0}^{P+Q}$  are the steering vectors corresponding to  $\{\theta_p\}_{p=0}^{P+Q}$ , and  $\mathbf{n}$  stands for the additive white Gaussian noise vector.  $\mathbf{x}_s = \mathbf{a}(\theta_0)s_0$  and  $\mathbf{x}_{\text{int}} = \sum_{p=1}^{P+Q} \mathbf{a}(\theta_p)s_p$  denote the SOI and interferences, respectively.

An adaptive beamformer can be written as follows:

$$\mathbf{z} = \mathbf{W}^H \mathbf{x} \quad (2)$$

where  $(\cdot)^H$  denotes the Hermitian transpose and  $\mathbf{W}$  is the weight vector.

The optimal solution of the weight vector is given by the following:

$$\mathbf{W}_{\text{opt}} = \frac{\mathbf{R}_{i+n}^{-1} \mathbf{a}(\theta_0)}{\mathbf{a}^H(\theta_0) \mathbf{R}_{i+n}^{-1} \mathbf{a}(\theta_0)} \quad (3)$$

where  $\mathbf{R}_{i+n} = E\{(\mathbf{x}_{\text{int}} + \mathbf{n})(\mathbf{x}_{\text{int}} + \mathbf{n})^H\}$  represents the interference-plus noise covariance matrix (INCM) of the received data. Since  $\mathbf{R}_{i+n}$  is unavailable in practical applications, it is generally replaced by the following sample covariance matrix (SCM):

$$\hat{\mathbf{R}} = \mathbf{x}\mathbf{x}^H/L \quad (4)$$

where  $L$  denotes the length of the data snapshots (typically,  $L \geq 2M$  is required to ensure the output SINR loss is less than 3 dB). By using the sample matrix inversion (SMI), the conventional adaptive weight vector can be calculated as follows:

$$\mathbf{W}_{\text{SMI}} = \frac{\hat{\mathbf{R}}^{-1} \mathbf{a}(\theta_0)}{\mathbf{a}^H(\theta_0) \hat{\mathbf{R}}^{-1} \mathbf{a}(\theta_0)} \quad (5)$$

The conventional SMI ABF in Eq. (5) may lead to pattern distortion in the case of mainlobe interference and the cancellation of the SOI when the SOI exists in the selected data sample. Meanwhile, it is vulnerable to SV mismatches.

## 2 Proposed Method

In this section, an improved algorithm based on IAA, BMP, and SINCM reconstruction techniques for multiple mainlobe interference suppression is proposed. The main idea is to discriminate the mainlobe interferences via the refined DOA estimation by IAA and the correlation coefficient calculation of direction SVs first. Then, mainlobe interferences are eliminated via BMP pretreatment. Lastly, the SINCM is reconstructed by applying IAA again and achieving the preferable ABF for residual interference suppression. The main innovation of the proposed algorithm lies in combining the reconstruction of the interference noise covariance matrix based on IAA accurate spectral estimation with BMP preprocessing methods to achieve multi-mainlobe interference suppression. The flowchart of the proposed algorithm is shown in Fig. 1.

### 2.1 IAA<sup>[28-29]</sup>

The IAA spectral estimation is a nonparametric adaptive algorithm based on the weighted least squares (WLS) approach<sup>[28]</sup>. Let  $\mathbf{S} = [\mathbf{S}_1, \mathbf{S}_2, \dots, \mathbf{S}_K]$  be the waveform vector of far-field potential signal sources located at  $\boldsymbol{\theta} \triangleq [\theta_1, \theta_2, \dots, \theta_K]$ , where  $\theta_k$  denotes the direction of the  $k$ -th potential source  $\mathbf{S}_k$ ,  $k = 1, 2, \dots, K$  ( $K \gg M$ ). Assume the imping angles of radiated sources are contained in  $\boldsymbol{\theta}$ . The basic idea of IAA is to es-



## 2.4 SINCM reconstruction and adaptive weight vector computation

To eliminate the residual sidelobe interferences, IAA is executed again on the preprocessed data  $\mathbf{y}$  for precise spatial spectrum estimation, reconstruct the SINCM, and figure out the preferable adaptive weight vector.

Let  $\mathbf{a}_b(\theta_k) \in \mathbb{C}^{(M-P) \times 1}$  be the SV of the  $k$ -th potential source  $\mathbf{S}_k$ ,  $k = 1, 2, \dots, K$ , and  $\mathbf{A}_b$  be the steering vector matrix defined as  $\mathbf{A}_b \triangleq [\mathbf{a}_b(\theta_1), \mathbf{a}_b(\theta_2), \dots, \mathbf{a}_b(\theta_K)]$ . After applying IAA again on  $\mathbf{y}$ , the estimated power matrix  $\tilde{\mathbf{P}}$  can be obtained as in Eq. (10), and the covariance matrix  $\hat{\mathbf{R}}$  can be calculated as follows:

$$\hat{\mathbf{R}} = \mathbf{A}_b \tilde{\mathbf{P}} \mathbf{A}_b^H = \sum_{i=1}^{M-P} \lambda_i \mathbf{e}_i \mathbf{e}_i^H \quad (17)$$

where  $\lambda_i$ ,  $i = 1, 2, \dots, M-P$  denotes the eigenvalues of  $\hat{\mathbf{R}}$  in the descending order and  $\mathbf{e}_i$  is the  $i$ -th eigenvector.

Assume that the desired signal lies in the known angular sector  $\Theta$ , and the SINCM can be reconstructed as follows [15]:

$$\bar{\mathbf{R}} = \sum_{\theta_k \in \Theta} \tilde{\mathbf{P}}_k \mathbf{a}_b(\theta_k) \mathbf{a}_b^H(\theta_k) + \sum_{\theta_k \in \bar{\Theta}} \bar{\sigma}^2 \mathbf{a}_b(\theta_k) \mathbf{a}_b^H(\theta_k) \quad (18)$$

$$\bar{\sigma}^2 = \frac{1}{M-P-Q-1} \sum_{i=Q+2}^{M-P} \lambda_i \quad (19)$$

where  $\bar{\Theta}$  is the complementary angular sector of  $\Theta$  and  $\bar{\sigma}^2$  is the noise power of the IAA spatial spectrum of  $\mathbf{y}$ . In Eq. (18), the source powers in angular sector  $\Theta$  are filled with noise power to make sure that the covariance matrix  $\bar{\mathbf{R}}$  is full rank.

Replacing  $\hat{\mathbf{R}}$  in Eq. (5) with  $\bar{\mathbf{R}}$ , the preferable adaptive weight vector  $\bar{\mathbf{W}}$  for better output SINR performance can be derived. The output data  $\mathbf{z}$  can be obtained as follows:

$$\mathbf{z} = \bar{\mathbf{W}}^H \mathbf{B} \mathbf{x} \quad (20)$$

The proposed suppression process of multiple mainlobe suppression interferences is summarized in Algorithm 1.

**Algorithm 1** The IAA-BMP-SINCM multiple mainlobe interference suppression

(1) Estimate spatial spectrum utilizing IAA and estimate the DOA of multiple interferences  $\{\hat{\theta}_p\}_1^{P+Q}$ .

(2) Generate SVs of the interferences according to the DOA estimation results. Compute the correlation coefficients  $\rho(\mathbf{a}(\hat{\theta}_p), \mathbf{a}(\theta_0))$  between each interference and the receive SVs, discriminating the mainlobe interferences and getting DOA estimations of multiple mainlobe interferences  $\{\hat{\theta}_{mi}\}_1^P$ , as in Eq. (13).

(3) Execute the BMP method and suppress the mainlobe interference components in the receiving snapshot data.

(4) Execute IAA spectral estimation again on the preprocessed data  $\mathbf{y}$  and reconstruct the SINCM  $\bar{\mathbf{R}}$  as in

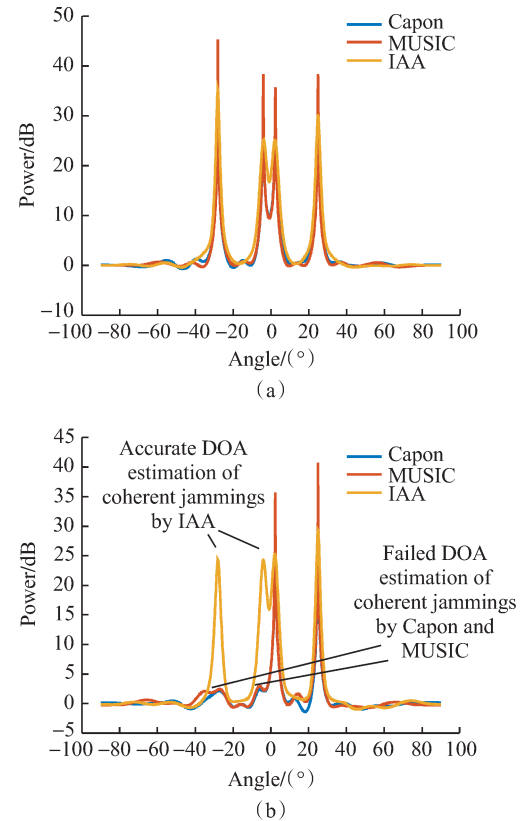
Eq. (18).

(5) Calculate the weight vector  $\bar{\mathbf{W}}$  using  $\bar{\mathbf{R}}$ , complete ABF in Eq. (20), and obtain output data  $\mathbf{z}$ .

## 3 Simulation Results

In the simulations, this study considered a ULA with  $M = 16$  elements spaced half a wavelength. The SOI direction was  $0^\circ$ , with a signal-to-noise ratio (SNR) of 0 dB. Two mainlobe interferences powered 25 and 25 dB are located at  $-4.0^\circ$  and  $2.38^\circ$ , and two sidelobe interferences powered 35 and 30 dB are imping from  $-28^\circ$  and  $25^\circ$ .

Fig. 2 shows the spatial spectral estimation results by using the IAA, Capon, and MUSIC algorithms (assuming the number of sources is preknown for MUSIC). In Fig. 2(a), all three methods have refined DOA estimation when the interferences are uncorrelated. However, IAA exhibits better accuracy in power estimation of the sources, which helps the more refined reconstruction of SINCM and calculation of  $\bar{\mathbf{W}}$ . In the case when part of the sources is coherent (i.e., sidelobe jammer at  $-28^\circ$  and mainlobe jammer at  $-4.0^\circ$ ), as shown in Fig. 2(b), the Capon and MUSIC algorithms fail to estimate the DOA of the coherent sources. The results demonstrate that IAA outperformed the other two algorithms under

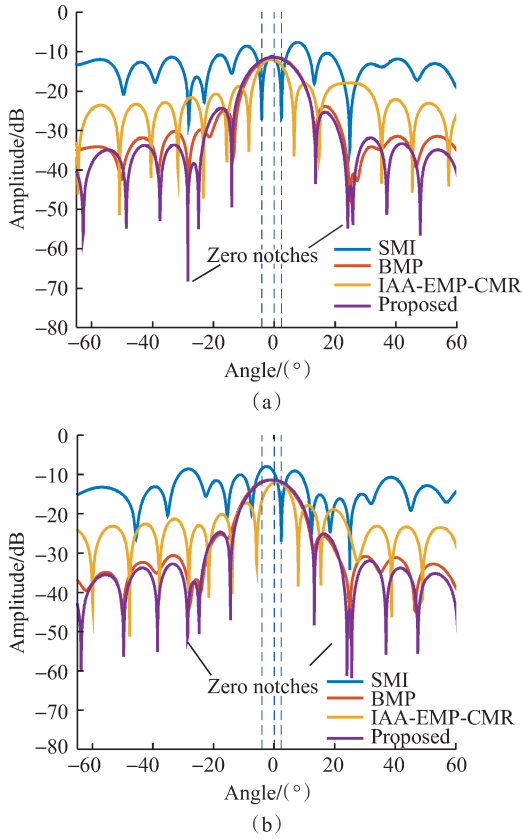


**Fig. 2** Comparison of spatial spectral estimation results under uncorrelated and coherent environments (snapshot number 100). (a) When all the mainlobe or sidelobe interferences are uncorrelated; (b) When one mainlobe and one sublobe interferences are coherent



both uncorrelated and coherent conditions.

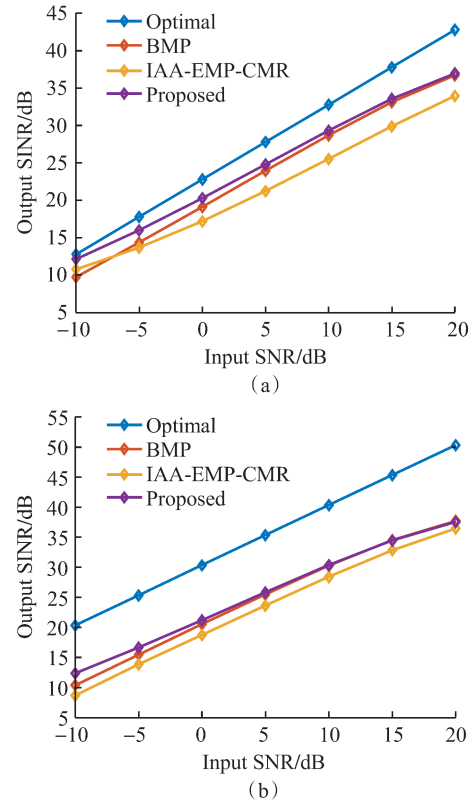
The different adaptive array patterns in one simulation are shown in Figs. 3(a) and (b). By contrast, the conventional SMI method suffers from mainlobe distortion and high sidelobe. The IAA-EMP-CMR method in Ref. [15] also suffers from high sidelobe and shallow zero notches in sidelobe interference directions, which may affect the angle measurement accuracy of the SOI and output SINR. Compared with the BMP method in Ref. [17], the proposed method has deeper zero notches and lower sidelobe and thus can sustain stronger sidelobe interferences under both uncorrelated and coherent conditions.



**Fig. 3** Adaptive array patterns of different methods for two mainlobe interference suppression. (a) When all the mainlobe or sidelobe interferences are uncorrelated (i.e., zero notches  $\leq -55$  dB by the proposed method); (b) When one mainlobe and one sublobe interferences are coherent (i.e., zero notches  $\leq -47$  dB by the proposed method)

Fig. 4 shows the output SINR performance of the proposed method, compared with the BMP method in Ref. [17] and the IAA-EMP-CMR method in Ref. [15] versus input SNR (supposing the SOI is not contained in snapshot samples for the BMP method in Ref. [17]). When all interferences are uncorrelated, as shown in Fig. 4(a), the output SINR by the proposed method is superior to the BMP and IAA-EMP-CMR methods as the input SINR varies from  $-10$  to  $20$  dB. When one mainlobe and one sidelobe interferences are coherent (Fig. 2

(b)), the output SINR performance by the proposed method still outperforms the IAA-EMP-CMR and BMP methods, particularly when the input SNR is lower than  $5$  dB, as shown in Fig. 4(b). When the input SNR is more than  $10$  dB, the output SINR performance of the proposed method is close to that of the BMP method and is still better than that of the IAA-EMP-CMR method. The degradation of output SINR performance is due to the increase in the power leakage of the SOI signal component over the angular sector  $\Theta$  in Eq. (18) as the input SNR raises to more than  $20$  dB. Overall, the simulation results verify the superiority of the proposed method in both uncorrelated and coherent situations.



**Fig. 4** Output SINR of different methods versus input SNR. (a) When all the mainlobe or sidelobe interferences are uncorrelated; (b) When one mainlobe and one sublobe interferences are coherent

Because the estimated matrix  $\hat{\mathbf{R}}$  or  $\bar{\mathbf{R}}$  is used to substitute the theoretical matrix  $\mathbf{R}_{i+n}$  for each method, the impact of the number of snapshots  $L$  on the output SINR should also be examined. Suppose the input SNR is  $0$  dB and the number of Monte Carlo runs is  $20$ . The influence of the number of snapshots  $L$  on the output SINR is shown in Fig. 5. The results show that the output SINR performance by the proposed method outperforms the IAA-EMP-CMR method, no matter how  $L$  changes. Because IAA can accurately estimate the spatial spectrum even in low snapshot situations, there is little change in the output SINR performance of the proposed method

and the IAA-EMP-CMR method as  $L$  decreased. However, the output SINR performance of the BMP method significantly decreases as  $L$  decreases. When  $L \leq 2M$ , the output SINR performance of the BMP method is worse than that of the IAA-EMP-CMR method. When  $L \geq 5M$ , the output SINR performance of the BMP method is slightly lower than that of the proposed method. Hence, the simulation results verify the superiority of the proposed method under different numbers of snapshots as a whole.

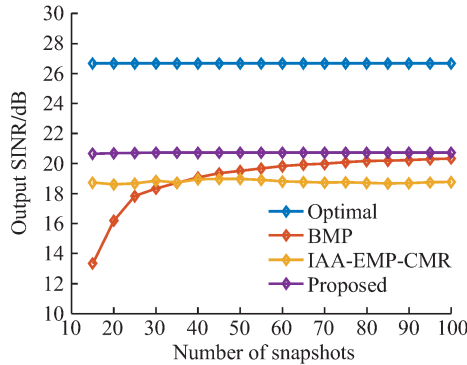


Fig. 5 Output SINR of different methods versus number of snapshots (input SNR is 0 dB)

#### 4 Conclusions

This paper has illustrated the array signal model and the principle of ABF and presented an improved approach for multiple mainlobe interference suppression to avoid the drawbacks of conventional methods. IAA has been proposed to accurately estimate the DOA and power of sources, which is superior to the Capon or MUSIC methods, particularly under coherent conditions. This paper has also applied the correlation coefficient calculation of direction SVs and BMP pretreatment to effectively discriminate and eliminate the mainlobe interferences. Furthermore, this paper has suggested reconstructing the SINCM by IAA spectral estimation of the preprocessed data for the final preferable ABF and residual interference suppression. The numerical simulations have shown that the proposed approach had better array patterns and output SINR performances compared with the conventional BMP method and the IAA-EMP-CMR method<sup>[15]</sup> under both uncorrelated and coherent circumstances.

#### References

- [1] SPEZIO A E. Electronic warfare systems [J]. IEEE Transactions on Microwave Theory and Techniques, 2002, 50(3): 633-644.
- [2] BUCKLEY K, GRIFFITHS L. An adaptive generalized sidelobe canceller with derivative constraints [J]. IEEE Transactions on Antennas and Propagation, 1986, 34(3): 311-319.
- [3] FARINA A. Electronic counter-countermeasures [M]// Radar Handbook. 3rd ed. New York, NY, USA: McGraw-Hill, 2008:10-15.
- [4] CHEN H, GUO X W, LIU C, et al. Optimal control method for complex nonlinear systems based on disturbance observer [J]. Journal of Southeast University (Natural Science Edition), 2024, 54(4): 1046-1052. (in Chinese)
- [5] ZHAO Y J, TIAN B, WANG C Y, et al. Research on main-lobe deceptive jamming against FDA-MIMO radar [J]. IET Radar, Sonar & Navigation, 2021, 15(6): 641-654.
- [6] LAN L, LIAO G S, XU J W, et al. Main-beam range deceptive jamming suppression approach with FDA-MIMO radar [J]. Systems Engineering and Electronics, 2018, 40(5): 997-1003.
- [7] HAN B W, LAN T, YANG X P. Beam-space-polarization domain main-lobe jamming suppression method for distributed array radar [J]. Modern Radar, 2021, 43(10): 21-26. (in Chinese)
- [8] NING L Y, YANG X P. Multi-base polarization radar main-lobe interference suppression algorithm [J]. Journal of Signal Processing, 2017, 33(12): 1571-1577. (in Chinese)
- [9] YANG X P, YIN P L, ZENG T. Mainlobe interference suppression based on large aperture auxiliary array [C]// 2012 IEEE Asia-Pacific Conference on Antennas and Propagation. Singapore, 2012: 317-318.
- [10] YANG X P, YIN P L, ZENG T, et al. Applying auxiliary array to suppress mainlobe interference for ground-based radar [J]. IEEE Antennas and Wireless Propagation Letters, 2013, 12: 433-436.
- [11] LI R F, WANG Y L, WAN S H. Robust adaptive beam forming under main lobe interference conditions [J]. Systems Engineering and Electronics, 2002, 24(7): 61-64. (in Chinese)
- [12] LI R F, WANG Y L, WAN S H. Research of reshaping adapted pattern under mainlobe interference conditions [J]. Modern Radar, 2002, 24(3): 50-53. (in Chinese)
- [13] CHEN Z, JIA W, JIN W, et al. Analysis of mainlobe interference suppression algorithms based on eigen-projection matrix preprocessing [J]. Modern Radar, 2020, 42(4): 55-60. (in Chinese)
- [14] YANG X P, ZHANG Z A, ZENG T, et al. Mainlobe interference suppression based on eigen-projection processing and covariance matrix reconstruction [J]. IEEE Antennas and Wireless Propagation Letters, 2014, 13: 1369-1372.
- [15] WANG Y S, BAO Q L, CHEN Z P. Robust mainlobe interference suppression for coherent interference environment [J]. EURASIP Journal on Advances in Signal Processing, 2016, 2016(1): 135.
- [16] YU S J, LEE J H. Efficient eigenspace-based array signal processing using multiple shift-invariant subarrays [J]. IEEE Transactions on Antennas and Propagation, 1999, 47(1): 186-194.
- [17] SU B W, WANG Y L, ZHOU L Z. A mainlobe interference cancelling method [C]//2005 IEEE International Symposium on Microwave, Antenna, Propagation and EMC Technologies for Wireless Communications. Bei-

- jing, China, 2005: 23-26.
- [18] PAN S, ZHANG Y S, GE Q C, et al. Multi-mainlobe interferences suppression based on interference covariance matrix reconstruction[J]. Journal of Physics: Conference Series, 2019, 1176: 042011.
- [19] HU H T, ZHANG J Y, LI X B, et al. Anti-mainlobe interference algorithm based on blocking matrix preprocessing[J]. Journal of Detection & Control, 2018, 40(5): 94-99. (in Chinese)
- [20] ZHANG M, SONG R, ZHANG X Y, et al. Main lobe jamming suppression algorithm based on blocking matrix pre-processing and covariance matrix reconstruction[C]// Eleventh International Conference on Signal Processing Systems. Chengdu, China, 2019.
- [21] ZHAO J, LIN L, DONG W. A new variable step-size LMS method and its application in DOA estimation of OFDMA signals [J]. Journal of Southeast University (English Edition), 2020, 36(2): 145-151.
- [22] WANG Q Y, ZHAO L, LIANG R Y, et al. Compressive sampling and DOA estimation method for miniature microphone array [J]. Journal of Southeast University (Natural Science Edition), 2014, 44(4): 687-691. (in Chinese)
- [23] WANG W X, WU Z Y, PENG Y X, et al. DOA estimation based on counteraction of interferences' correlation matrices [J]. Journal of Southeast University (Natural Science Edition), 2004, 34(3): 301-304. (in Chinese)
- [24] STOICA P, MOSES R L. Spectral analysis of signals [M]. Upper Saddle River, NJ, USA: Pearson Prentice Hall, 2005: 5-15.
- [25] ZHANG Y F, CHEN X, ZHANG J C, et al. Multi-object tracking based on deep aggregation high-resolution network[J]. Journal of Southeast University (Natural Science Edition), 2023, 53(1): 14-20. (in Chinese).
- [26] SCHMIDT R. Multiple emitter location and signal parameter estimation[J]. IEEE Transactions on Antennas and Propagation, 1986, 34(3): 276-280.
- [27] LI A Q, ZHANG C, ZHONG G Q, et al. Automatic identification method for structural modal parameters based on stochastic subspace identification [J]. Journal of Southeast University (Natural Science Edition), 2023, 53(1): 53-60. (in Chinese)
- [28] STOICA P, LI J, HE H. Spectral analysis of nonuniformly sampled data: A new approach versus the periodogram [J]. IEEE Transactions on Signal Processing, 2009, 57(3): 843-858.
- [29] YARDIBI T, LI J, STOICA P, et al. Source localization and sensing: A nonparametric iterative adaptive approach based on weighted least squares[J]. IEEE Transactions on Aerospace and Electronic Systems, 2010, 46(1): 425-443.

## 非相关/相干环境下多主瓣干扰抑制改进算法

蔡苗红, 程强, 孟晋丽, 赵德华

(南京电子技术研究所, 南京 210039; 雷达探测感知全国重点实验室, 南京 210039;  
江苏省探测感知技术重点实验室, 南京 210039)

**摘要:** 为研究多主瓣干扰抑制, 提出了一种基于迭代自适应算法(IAA)与阻塞矩阵预处理(BMP)的新方法。为克服常规自适应波束形成(ABF)方法存在的缺陷, 提出了应用 IAA 进行空间谱的准确估计与干扰源到达方向(DOA)的准确估计, 其中主瓣干扰分量主要通过方向导向矢量(SVs)之间相干系数的计算进行识别, 并利用阻塞矩阵预处理(BMP)进行剔除。利用 IAA 进行旁瓣干扰与噪声协方差矩阵重构, 从而实现更优 ABF 与剩余干扰抑制。仿真结果表明, 无论在非相关或相干干扰环境下, 所提方法与常规基于 BMP 或特征投影矩阵预处理(EMP)的方法相比均具有更优性能。

**关键词:** 主瓣干扰抑制; 自适应波束形成(ABF); 空间谱估计; 迭代自适应算法(IAA); 阻塞矩阵预处理(BMP)

中图分类号: TN95