

Monopulse-Based Blind-Spot Correction using a Full-Azimuthal Leaky-Wave Antenna Array

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Abstract— This paper presents a theoretical full-azimuthal angle estimation algorithm for ISAC systems based on a triangular array of bi-directional leaky-wave antennas. The impact of angular blind spots on amplitude-monopulse estimation is analyzed, and a lightweight deep-learning correction is introduced to improve angular robustness without increasing system complexity.

Keywords— Localization, Leaky-Wave Antennas, Integrated Sensing and Communication, Deep-Learning.

I. INTRODUCTION

Integrated sensing and communication (ISAC) has emerged as a key paradigm for future wireless systems by combining localization and communication functionalities within a unified framework, where accurate direction finding is essential for reliable positioning and beamforming [1]. In this context, leaky-wave antennas (LWAs) offer compact implementations and inherent beam-scanning capabilities, enabling wide angular coverage with reduced hardware complexity [2]. However, single-element and multi-element LWA-based configurations often exhibit limited or non-uniform azimuthal responses, especially in full-azimuth architectures, leading to angular blind spots where directive radiation is weak or absent [3]. These blind-spot regions introduce systematic degradation in classical angle estimation techniques using antenna arrays [4], such as amplitude monopulse, due to reduced signal observability. Moreover, it is not a case that can be only applied to power information algorithms, but it can be observed in phased arrays and complex amplitude and phase localization algorithms. Recent data-driven methods have shown potential to complement model-based processing by learning correction patterns associated with such systematic distortions. Motivated by this, this work provides a simplified theoretical framework that analyzes blind-spot effects in full-azimuth LWA-based ISAC systems and introduces a lightweight learning-assisted correction to improve angular robustness without increasing antenna or system complexity. A schematic of the blind spot problem can be observed in Fig. 1.

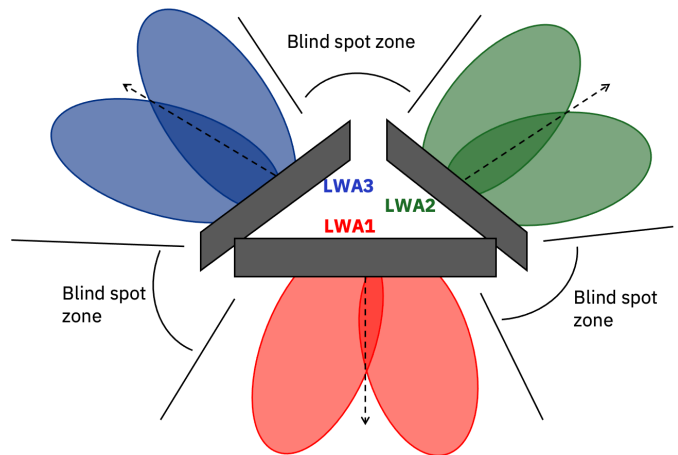


Fig. 1 Proposed leaky-wave antenna array geometry for full-azimuthal coverage.

II. METHODS

The proposed full-azimuth direction-finding architecture is based on three identical bidirectional leaky-wave antennas arranged in an equilateral triangular configuration to enable 360° azimuthal coverage. Each antenna generates two directive beams when excited from opposite ports, providing wide angular coverage with a compact and low-complexity structure. By properly orienting the three elements, the array covers the full azimuth through the superposition of their radiation patterns. However, due to the finite beamwidth and non-overlapping regions between adjacent beams, certain angular sectors exhibit reduced radiation levels, referred to as angular blind spots. In these regions, the signal amplitude is significantly attenuated, which inherently limits the accuracy of classical amplitude-monopulse direction-of-arrival estimation. This work adopts a simplified theoretical radiation model of the array to analyze the impact of blind spots on angle estimation performance and to serve as a reference framework for the comparison between monopulse-based and learning-based estimation strategies.

The direction-of-arrival (DoA) estimation problem can be addressed using classical amplitude monopulse processing, which exploits the relative power differences between pairs of directive beams. Let us consider a multi-port antenna system characterized by its angular power response.

For a signal arriving from an unknown direction θ_0 , the received power at the m -th port can be expressed as:

$$P_m[k] = P_s \cdot g_m(\theta_0) + w_m[k]$$

where P_s denotes the transmitted signal power, $g_m(\theta)$ is the radiation pattern associated with the m -th port, and $w_m[k]$ represents additive noise, typically modeled as a zero-mean Gaussian random variable.

By combining multiple ports, a vector observation can be defined as:

$$p[k] = P_s \cdot g(\theta_0) + w[k]$$

where $g(\theta)$ contains the angular responses of all ports.

For each pair of beams (i, j), a monopulse ratio is constructed using the sum and difference of received powers:

$$\Sigma_{ij} = P_i + P_j; \Delta_{ij} = P_i - P_j$$

The corresponding monopulse observable is defined as:

$$MV_{ij} = (P_i - P_j) / (P_i + P_j)$$

This ratio provides an estimate of the angular deviation relative to the boresight (or symmetry axis) between the two beams.

In the vicinity of the beam crossover region, the monopulse function exhibits an approximately linear behavior:

$$MV(\theta) \approx K \cdot (\theta - \theta_{ref})$$

where K is the monopulse slope and θ_{ref} is the reference direction (typically the midpoint between the two beams). This linearity enables a direct inversion to estimate the angle.

To improve robustness, the monopulse value is compared against its theoretical angular response. For each beam pair, a pseudospectrum is defined as:

$$APS_n(\theta) = -10 \log_{10} (1 / | MF_n(\theta) - MV_n |)$$

where $MF_n(\theta)$ denotes the theoretical monopulse function associated with the n -th beam pair.

The different pseudospectra are then combined to form a global angular response:

$$APS(\theta) = F \{ APS_1(\theta), APS_2(\theta), \dots, APS_N(\theta) \}$$

where $F\{\cdot\}$ represents a fusion operator (e.g., averaging or maximum selection).

Finally, the DoA estimate is obtained as the peak with the maximum amplitude.

From a theoretical standpoint, monopulse technique provides low-complexity and physically interpretable DoA estimation. Its accuracy is maximized in regions where the radiation

patterns overlap significantly and the monopulse slope remains linear. However, when the received power is weak or the beam overlap is limited, the monopulse ratio becomes highly nonlinear, leading to large estimation errors. These regions can be interpreted as low-observability zones in the angular domain, where classical estimators lose reliability.

To overcome the intrinsic nonlinearities of the antenna response and the limitations of analytical inversion, the DoA estimation problem can be reformulated as a supervised learning task.

Let $x \in \mathbb{R}^{(M \times K)}$ denote the input data matrix, containing K temporal snapshots of the received power across M antenna ports. The goal is to learn a nonlinear mapping:

$$\theta = f(x)$$

where $f(\cdot)$ is a parametric function implemented by a neural network.

A lightweight convolutional neural network (CNN) can be employed to extract relevant features from the input data. The processing pipeline consists of:

1. A one-dimensional convolution layer applied along the snapshot dimension.
2. A nonlinear activation function (e.g., ReLU).
3. A global pooling stage to aggregate temporal information.

The convolution operation can be expressed as:

$$h = \sigma(W * x + b)$$

where W represents the convolution kernels, b is the bias term, and $\sigma(\cdot)$ denotes the nonlinear activation.

Instead of directly estimating θ , the model predicts a continuous angular embedding:

$$\hat{y} = [\hat{y}_1, \hat{y}_2] = [\sin(\theta), \cos(\theta)]$$

This representation avoids discontinuities at the angular boundaries ($\pm 180^\circ$) and ensures smooth learning behavior.

The final DoA estimate is recovered as:

$$\theta = \text{atan2}(\hat{y}_1, \hat{y}_2)$$

The network is trained using a mean squared error loss between predicted and true angular embeddings:

$$L = (1/N) \sum \|\hat{y}_i - y_i\|^2$$

where:

$$y_i = [\sin(\theta_i), \cos(\theta_i)]$$

and N is the number of training samples.

From a theoretical viewpoint, deep learning enables the approximation of highly nonlinear mappings between electromagnetic observations and angular parameters. This is particularly advantageous in scenarios where the antenna response is irregular or where classical assumptions (e.g., linear

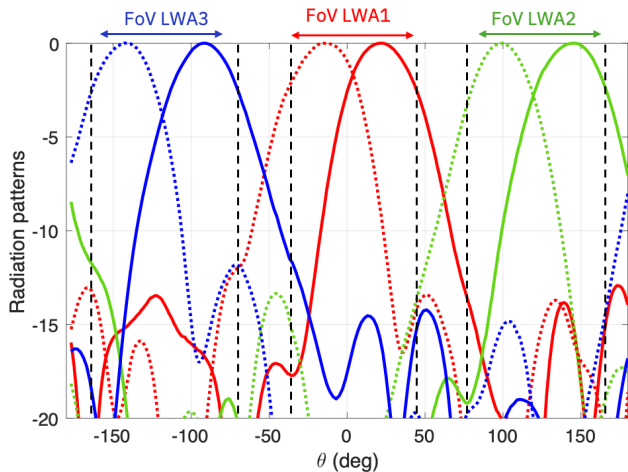


Fig. 2. Simulated normalized full azimuthal leaky wave antenna array radiation patterns. Solid line: port 1 of each individual LWA. Dotted line: port 2 o

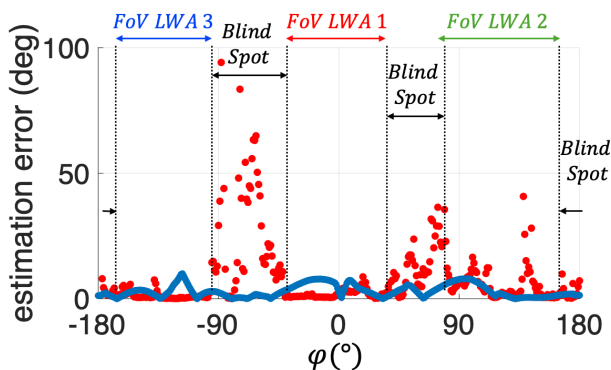


Fig. 3. Absolute angular error of the proposed algorithms over the full range. Red dots, monopulse algorithm. Blue dots, monopulse deep-learning reinforced algorithm.

monopulse behavior) do not hold.

Unlike analytical methods, the deep-learning algorithm implicitly learns the inverse mapping without requiring explicit knowledge of the radiation patterns. However, its performance depends on the representativeness of the training dataset and the generalization capability of the model.

III. RESULTS AND DISCUSSION

The performance of the proposed direction-of-arrival estimation approaches is evaluated over the full azimuth range from -180° to 180° using simulated snapshots at a fixed signal-to-noise ratio of 10 dB. The radiation patterns of the leaky-wave antenna array are plotted in Fig. 2. The angular estimation error across the complete field of view is illustrated in Fig. 3, while the overall trends are discussed in terms of robustness and accuracy. As observed, the classical amplitude-monopulse method provides accurate angle estimates in regions where the antenna radiation exhibits sufficient directive gain. However, its performance degrades significantly in angular blind-spot sectors, where reduced signal amplitude leads to nonlinear

monopulse ratios and large estimation errors.

In contrast, the deep-learning-based approach maintains a more uniform estimation accuracy across the full azimuth. By learning the underlying relationship between the received signal amplitudes and the angle of arrival, the model is able to compensate for the systematic distortions introduced by blind-spot regions, effectively reducing large angular outliers.

Overall, these results highlight the limitations of purely model-based monopulse estimation in full-azimuth LWA systems and demonstrate that even a simple data-driven approach can significantly enhance angular robustness in blind-spot regions without increasing system or antenna complexity.

IV. CONCLUSION

This paper has compared classical amplitude-monopulse estimation with a deep-learning-based approach for full-azimuth direction-of-arrival estimation using LWA arrays. While monopulse provides a simple and physically interpretable solution, its performance degrades in angular blind-spot regions. The learning-based method improves angular accuracy across the azimuth by compensating for systematic distortions, demonstrating its potential as a low-complexity enhancement for blind-spot mitigation in ISAC systems.

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REFERENCES

- [1] W. Chen et al., "5G-Advanced Toward 6G: Past, Present, and Future," in *IEEE Journal on Selected Areas in Communications*, vol. 41, no. 6, pp. 1592-1619, June 2023.
- [2] A. Gil-Martinez et al., "Monopulse leaky wave antennas for RSSI based direction finding in wireless local area networks", in *IEEE Trans. Antennas Propag.*, vol. 71, no. 11, pp. 8602-8615, 2023.
- [3] M. Temiz et al., "Deep-learning based techniques for integrated sensing and communication systems: state of the art, challenges and opportunities," in *IEEE Open Journal of the Communication Society*, vol. 6, pp. 5940-5968, 2025.
- [4] T. Crépin et al., "Blind spot mitigation in phased array antenna using metamaterials," *2014 International Radar Conference*, Lille, France, 2014, pp. 1-4.