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ADVANCED ELECTRON DEVICES AND SYSTEMS FOR ENHANCED PERFORMANCE IN RADAR AND SONAR APPLICATIONS

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Abstract

Radar and sonar systems are crucial for various applications, including surveillance, navigation, and environmental monitoring. However, traditional methods often struggle with noise interference, bandwidth limitations, and computational inefficiencies, leading to reduced detection accuracy and slower processing times. To address these challenges, a novel method is proposed that leverages advanced electron devices optimized for high-frequency operations and a hybrid simulation approach, enhancing the performance of radar and sonar systems. The proposed method was evaluated across two frequency ranges: 1 GHz to 10 GHz for radar and 1 kHz to 100 kHz for sonar. The results demonstrated substantial improvements in key performance metrics. The Signal-to-Noise Ratio (SNR) achieved 16.8 dB for radar and 25.6 dB for sonar, surpassing existing methods such as HFSS and CST Microwave Studio, which recorded SNRs of 14.2 dB and 21.0 dB, respectively. Bandwidth Utilization (BU) also improved significantly, reaching 85% for radar and 80% for sonar, compared to the maximum of 72% for HFSS. Detection Accuracy (DA) increased to 90% for radar and 88% for sonar, while Computational Efficiency (CE) rose to 200 iterations per second for radar and 180 iterations per second for sonar, outperforming all existing methods in both frequency ranges. These results underscore the proposed method's effectiveness in enhancing radar and sonar system performance, providing clearer signals, higher detection rates, and faster processing times. The advancements presented herein not only address existing limitations but also offer a pathway for future innovations in radar and sonar technology.

Keywords:

Radar, Sonar Systems, Bandwidth Utilization, HFSS

1. INTRODUCTION

The advancement of radar and sonar systems has significantly impacted a range of applications, from military surveillance to civilian navigation and search-and-rescue operations. Modern systems rely on high-frequency signal processing and precise detection mechanisms to function optimally. Over the past decade, significant strides have been made in developing electron devices that enhance the sensitivity and resolution of these systems [1] [2]. Integrating sophisticated signal processing algorithms and high-performance hardware has enabled improved target detection, range resolution, and adaptability [3].

However, challenges remain in achieving consistent performance, especially in complex environments. Factors such as multipath interference, high ambient noise levels, and variable atmospheric conditions introduce significant obstacles to maintaining signal clarity and detection accuracy [4] [5]. Additionally, traditional methods often face limitations in terms of energy efficiency and processing speed, which can impede real-time system responsiveness [6] [7]. These issues highlight the need for innovative solutions that blend cutting-edge computational techniques with advanced hardware optimizations.

The core problem lies in bridging the performance gap in radar and sonar systems under challenging operational conditions, which includes enhancing signal processing to maintain accuracy while optimizing energy use and computational resources [8] [9]. Existing approaches, while robust in controlled settings, may fail to meet the demands of diverse environments, leading to a reduction in system effectiveness and reliability.

The objectives of this study are:

- To design and evaluate advanced electron devices integrated with enhanced signal processing frameworks.
- To improve signal-to-noise ratio (SNR), bandwidth utilization, detection accuracy, and computational efficiency.
- To benchmark the proposed solution against traditional methods and identify its advantages in performance metrics.

The novelty of this work lies in the application of hybrid simulation techniques using MATLAB and COMSOL Multiphysics that leverage both electromagnetic and acoustic modeling capabilities. The contributions of this research include developing an integrated simulation environment that combines time-domain and frequency-domain analyses for radar and sonar applications. Introducing an optimized framework for signal processing that balances computational load with real-time response needs.

2. RELATED WORKS

Radar and sonar systems have evolved through decades of innovation, marked by substantial research into signal processing and electronic device design [8]. The Finite-Difference Time-Domain (FDTD) method has long been employed to simulate electromagnetic wave propagation, offering a detailed approach to analyzing complex interactions within various mediums [9]. However, the FDTD method often requires significant computational resources, limiting its use in real-time applications. Comparatively, the Method of Moments (MoM) is frequently used for surface current evaluations but can become computationally intensive when scaling up to larger domains [10].

The development of tools such as CST Microwave Studio and ANSYS HFSS has contributed to enhancing the simulation and prototyping of high-frequency systems [11]. These software tools support intricate 3D modeling of electromagnetic interactions, enabling researchers to evaluate the impact of design changes on system performance. Nevertheless, while robust, these methods are sometimes constrained by high processing times and limited integration with broader signal processing frameworks [12].

More recent studies have introduced multi-mode and multi-path propagation models to mimic realistic environments, addressing issues of signal degradation due to reflections and environmental obstacles [13]. While these approaches improve simulation accuracy, their dependence on high-end computing infrastructure presents a scalability challenge. Techniques using adaptive mesh refinement within simulation tools have shown promise in mitigating these challenges, allowing for more efficient resource allocation during high-resolution analysis [14].

Furthermore, developments in hybrid simulation techniques, which combine electromagnetic and acoustic modeling, have proven beneficial for sonar systems. Acoustic modeling with tools like COMSOL Multiphysics helps simulate the propagation of sound waves in water and other mediums, providing valuable insights into sonar system behavior in different conditions [15]. Yet, while these hybrid models offer deeper analysis, their computational demand can still be prohibitive for real-time usage, particularly in dynamic or noisy environments.

In addressing computational efficiency, advancements such as parallel computing and GPU acceleration have been explored to reduce processing times and enhance performance [12] [13]. Implementing signal processing algorithms tailored for high-performance GPUs has yielded faster simulations and the potential for real-time applications. This integration supports applications that demand quick responses, such as search-and-rescue operations and tactical defense [14] [15].

Thus, while substantial progress has been made in improving radar and sonar systems through advanced simulation and electronic device integration, challenges persist in balancing the need for high-fidelity analysis with computational efficiency. The current study aims to address these gaps by introducing a scalable, high-performance framework that enhances the core performance metrics crucial for radar and sonar applications.

3. METHODS

The proposed method integrates advanced electron devices with a hybrid simulation approach to enhance the performance of radar and sonar systems in frequency-based applications. The process begins with the design and configuration of the electron devices optimized for high-frequency operations, utilizing materials and circuit structures that improve signal integrity and reduce noise interference. The simulation framework employs MATLAB and COMSOL Multiphysics, allowing a combination of time-domain and frequency-domain analyses. First, the radar or sonar system's signal pathways and environmental variables are modeled in COMSOL, focusing on wave propagation and multipath effects. The data from this phase feed into MATLAB for signal processing optimization, where algorithms are customized to enhance the Signal-to-Noise Ratio (SNR) and bandwidth utilization. These algorithms leverage GPU acceleration to handle complex operations swiftly, ensuring real-time response capability. Next, a series of test cases under varying conditions, such as high-noise and multi-path environments, are run to analyze system performance, with parameters adjusted iteratively to refine the results. The outputs are benchmarked against traditional simulation techniques like FDTD, HFSS, and CST Microwave Studio, focusing on metrics such as detection accuracy and computational efficiency. Finally, the results are evaluated and analyzed to validate the enhancements, ensuring the method's scalability and adaptability for diverse radar and sonar applications.

3.1 SIGNAL PATHWAYS AND ENVIRONMENTAL VARIABLES

The working of the proposed radar or sonar system's signal pathways involves understanding the interaction of electromagnetic or acoustic waves with their environment, which includes the transmission, reflection, and reception of signals. In both radar and sonar applications, signals are emitted from a transmitter, propagate through the medium, interact with objects, and return to the receiver. This process can be described mathematically using several fundamental equations.

The propagation of waves can be modeled using the wave equation, which describes how waves travel through a medium. In the case of electromagnetic waves, the wave equation in a vacuum is expressed as:

$$\nabla^2 E - \frac{1}{c^2}\frac{\partial^2 E}{\partial t^2} = 0 \tag{1}$$

where E represents the electric field, ccc is the speed of light in the medium, and ∇^2 is the Laplacian operator. For sonar, the analogous acoustic wave equation can be written as:

$$\nabla^2 p - \frac{1}{c^2}\frac{\partial^2 p}{\partial t^2} = 0 \tag{2}$$

where p denotes the acoustic pressure field and ccc is the speed of sound in the medium. Both equations describe how the respective waves propagate through space over time.

As the emitted waves encounter objects or boundaries, they undergo reflection and refraction, described by Snell's Law and the law of reflection. The law of reflection states:

$$\theta_i = \theta_r \tag{3}$$

where θ_i is the angle of incidence and θ_r is the angle of reflection. Snell's Law is expressed as:

$$n_1 \sin(\theta_i) = n_2 \sin(\theta_t) \tag{4}$$

where n_1 and n_2 are the refractive indices of the two media, and θ_t is the angle of transmission. These principles are essential for modeling how waves behave upon striking surfaces, influencing the received signal's amplitude and phase.

The signals reflected or refracted from targets are then captured by the receiver. The received signal strength can be characterized by the radar range equation for radar systems, which is given by:

$$P_r = P_t G_t G_r \frac{\lambda^2 \sigma}{(4\pi)^3 R^4} \tag{5}$$

where,

P_r is the received power,

P_t is the transmitted power,

G_t and G_r are the gains of the transmitting and receiving antennas, respectively,

λ is the wavelength of the signal,

σ is the radar cross-section of the target, and

R is the range to the target.

For sonar systems, a similar equation can be used to express the received signal intensity based on the source level and transmission loss, taking into account factors such as geometric spreading and absorption in the medium.

The effectiveness of the system is significantly influenced by environmental variables such as temperature, salinity, and ambient noise levels. These factors can be represented in the equations by modifying the speed of sound for sonar applications or by introducing attenuation factors for radar signals. For example, the speed of sound in water can be modeled as:

$$c = c_0 + \alpha(T - T_0) + \beta(S - S_0) + \gamma(P - P_0) \tag{6}$$

where c_0 is the reference speed of sound, T is temperature, S is salinity, and P is pressure. The coefficients α, β, and γ are empirical constants. Thus, these equations and principles form the foundation for modeling the signal pathways and environmental interactions in the proposed radar or sonar system. They enable accurate simulations that can predict system performance under varying conditions, facilitating the development of robust signal processing algorithms to enhance detection capabilities and reliability.

4. HYBRID SIMULATION APPROACH

The proposed hybrid simulation approach combines electromagnetic and acoustic modeling to provide a comprehensive analysis of radar and sonar systems under various environmental conditions. This methodology integrates both Finite-Difference Time-Domain (FDTD) methods and Finite Element Methods (FEM), allowing for an in-depth exploration of wave propagation characteristics while addressing the challenges associated with complex geometries and varying media.

4.1 WAVE PROPAGATION MODELING

The core of the hybrid approach begins with the **FDTD method** for electromagnetic wave simulation, which is particularly useful for understanding the behavior of radar signals. The FDTD algorithm discretizes Maxwell's equations, which govern electromagnetic wave propagation, into a grid-based format. The time-domain version of Maxwell's curl equations can be expressed as:

$$\frac{\partial \mathbf{E}}{\partial t} = \frac{1}{\text{ò}}\left(\nabla \times \mathbf{H}\right) - \sigma \mathbf{E} \tag{7}$$

$$\frac{\partial \mathbf{H}}{\partial t} = -\frac{1}{\mu}\left(\nabla \times \mathbf{E}\right) \tag{8}$$

where **E** is the electric field vector, **H** is the magnetic field vector, ϵ is the permittivity of the medium, μ is the permeability, and σ is the conductivity. By iterating over time and updating the electric and magnetic fields, the FDTD method effectively captures how electromagnetic waves propagate, reflect, and refract within various environments. For sonar applications, the FEM is employed to solve the wave equation in complex geometries, particularly when the medium is heterogeneous or exhibits irregular boundaries. The acoustic wave equation in the frequency domain is given by:

$$\nabla \cdot \left(\frac{1}{\rho}\nabla p\right) = -\omega^2 p \tag{9}$$

where p is the acoustic pressure, ρ is the density of the medium, and ω is the angular frequency. FEM discretizes the domain into finite elements, allowing for flexible modeling of wave behavior in realistic environments, such as underwater landscapes or structures that scatter sonar signals.

The integration of FDTD and FEM is achieved by employing a coupled solver approach. Initially, the electromagnetic characteristics of the radar system are simulated using the FDTD method to evaluate the initial signal propagation and interaction with potential targets. Simultaneously, the FEM is utilized to simulate the sonar signal propagation, accounting for variations in water properties such as temperature and salinity, which can affect sound speed. The results from the electromagnetic simulation provide boundary conditions for the acoustic model. For instance, the reflected power from a target detected by the radar can be input into the sonar model to assess how those targets would be imaged or detected in the acoustic domain. This is done by employing the impedance boundary condition, where the acoustic pressure is influenced by the radar reflection coefficient R:

$$p_r = R \cdot p_i \tag{10}$$

where p_r is the pressure of the reflected acoustic wave, and p_i is the pressure of the incident wave from the radar system.

Incorporating environmental variables into the simulation enhances the realism and accuracy of the results. Both FDTD and FEM models can include modifications based on temperature, salinity, and pressure, which affect wave propagation. For example, the speed of sound in water can be adjusted using the empirical formula mentioned previously as in Eq.(6). Additionally, attenuation due to absorption and scattering can be integrated into the wave equations, allowing for realistic modeling of signal degradation over distance. The absorption coefficient αa\alpha_aαa can be introduced in the wave equation:

$$\nabla^2 p + \alpha_a p = 0 \tag{11}$$

The hybrid simulation approach provides a powerful framework for modeling radar and sonar systems by leveraging the strengths of both FDTD and FEM techniques. By allowing for detailed electromagnetic and acoustic analyses, this approach enhances the ability to predict system performance in complex environments, paving the way for improved signal processing algorithms and better overall detection capabilities in radar and sonar applications. Through iterative testing and validation against real-world conditions, the hybrid model supports advancements in both theoretical understanding and practical application.

4.2 ELECTRON DEVICES OPTIMIZED FOR HIGH-FREQUENCY OPERATIONS

The proposed electron devices optimized for high-frequency operations are designed to enhance the performance of radar and sonar systems by improving signal integrity, reducing noise, and increasing overall system efficiency. These devices leverage advanced semiconductor materials and innovative circuit architectures to achieve superior operational characteristics at high frequencies, typically in the gigahertz (GHz) range or higher.

At the heart of these optimized electron devices are High Electron Mobility Transistors (HEMTs), which are particularly effective for high-frequency applications due to their high electron mobility and low noise characteristics. HEMTs utilize a heterostructure, typically composed of gallium arsenide (GaAs) or gallium nitride (GaN), to create a two-dimensional electron gas (2DEG) at the interface of two semiconductor materials. This structure allows for efficient charge transport, which can be mathematically described by the Drude model for electron motion:

$$\mathbf{J} = nq\mathbf{v} \tag{12}$$

where **J** is the current density, n is the charge carrier density, q is the charge of an electron, and **v** is the drift velocity of the charge carriers. The mobility μ of the electrons can be expressed as:

$$\mu = \frac{q\tau}{m^*} \tag{13}$$

where τ is the average time between collisions (scattering time) and m^* is the effective mass of the electron. The high mobility of electrons in HEMTs enables rapid switching and high-frequency operation, making them ideal for radar and sonar applications where fast signal processing is crucial.

In radar and sonar systems, signal amplification is critical for detecting weak signals in noisy environments. The performance of the HEMT can be characterized by its transduction gain G, which is defined as the ratio of output power Pout to input power Pin:

$$G = \frac{P_{\text{out}}}{P_{\text{in}}} \tag{14}$$

The gain-bandwidth product (GBP) is another vital metric that describes the frequency range over which the device can operate effectively. This can be expressed as:

$$GBP = G \times f_c \tag{15}$$

where f_c is the cutoff frequency at which the gain begins to roll off. By optimizing the design parameters of the HEMT, such as gate length, dielectric materials, and the doping profile of the semiconductor, the GBP can be maximized to ensure robust performance at high frequencies.

Minimizing noise is critical for high-frequency operation, especially in radar and sonar systems where weak signals are present. The noise figure (NF) is a key parameter that quantifies the degradation of the signal-to-noise ratio (SNR) as it passes through the device. The NF can be expressed as:

$$NF = 10\log_{10}\left(\frac{SNR_{\text{in}}}{SNR_{\text{out}}}\right) \tag{16}$$

where SNR_{in} is the input SNR and SNR_{out} is the output SNR. HEMTs can be designed to have low NF values by optimizing the device geometry and choosing suitable materials that exhibit low intrinsic noise characteristics, thereby enhancing the overall sensitivity of radar and sonar systems.

The efficiency of electron devices in radar and sonar applications is also paramount, particularly for portable and battery-operated systems. The power-added efficiency (PAE) quantifies how effectively the device converts DC power into RF output power and is given by:

$$PAE = \frac{P_{\text{out}} - P_{\text{in}}}{P_{\text{DC}}} \tag{17}$$

where P_{DC} is the DC power supplied to the device. High PAE values indicate that a significant portion of the input power is converted into useful output power, minimizing energy waste and heat generation.

The electron devices optimized for high-frequency operations into radar and sonar systems is instrumental in achieving enhanced performance metrics such as gain, noise reduction, and power efficiency. By leveraging advanced semiconductor technologies like HEMTs and focusing on design optimization for high-frequency characteristics, these devices significantly improve the systems' capabilities to detect and process signals in challenging environments. This advancement not only enhances detection accuracy but also contributes to the overall robustness and reliability of radar and sonar applications.

5. EXPERIMENTS

The experimental setup for evaluating the performance of advanced electron devices and systems in radar and sonar frequency applications involves the use of specialized simulation tools and high-performance computing resources. The simulations are conducted using MATLAB and COMSOL Multiphysics for modeling the electromagnetic behavior and acoustic wave propagation in radar and sonar systems. Comparisons are drawn with four existing benchmark methods:

- Finite-Difference Time-Domain (FDTD) Method for detailed electromagnetic analysis.
- High-Frequency Structure Simulator (HFSS) for 3D electromagnetic modeling.
- Method of Moments (MoM) for evaluating surface currents.
- CST Microwave Studio for complex radar and sonar system simulations.

Table.1. Parameters

Parameter	Value/Configuration
Frequency Range	1 GHz to 10 GHz for radar; 1 kHz to 100 kHz for sonar
Sampling Rate	2x the highest frequency component
Simulation Time Step	0.01 ms
Analysis Domain	Full-wave electromagnetic/ Acoustic domain
Environmental Conditions	Variable noise levels, multi-path effects
Number of Trials	100 for each test configuration

5.1 PERFORMANCE MEASURES

- **Signal-to-Noise Ratio (SNR)**: Measures the clarity of the signal in the presence of noise, expressed in decibels (dB). Higher SNR indicates better system performance in distinguishing signals from background noise.

- **Bandwidth Utilization**: Refers to how effectively the frequency spectrum is used during operation. Higher utilization implies that the system can achieve better resolution and target detection.
- **Detection Accuracy**: The proportion of correctly identified signals or targets out of total attempts. This metric evaluates how reliably the system detects and distinguishes valid targets under different conditions.
- **Computational Efficiency**: Assesses the time and resource consumption of the simulation and device performance. This is crucial for understanding how quickly and effectively the system can process and analyze data, with lower computation time being preferable.

Table.2. SNR

Frequency Range	Method	SNR (dB)
1 GHz - 10 GHz	FDTD	12.5
	HFSS	14.2
	MoM	13.0
	CST Microwave Studio	13.5
	Proposed Method	16.8
1 kHz - 100 kHz	FDTD	20.1
	HFSS	22.4
	MoM	21.5
	CST Microwave Studio	21.0
	Proposed Method	25.6

The proposed method demonstrates a notable improvement in SNR across both radar and sonar frequency ranges. For radar, the proposed method achieves an SNR of 16.8 dB, significantly surpassing the existing methods, with HFSS at 14.2 dB being the closest competitor. This enhanced SNR indicates that the proposed method is more effective at filtering out noise and improving signal clarity, which is crucial for accurate target detection in radar systems. In the sonar frequency range of 1 kHz to 100 kHz, the proposed method exhibits an even greater advantage, achieving an SNR of 25.6 dB compared to HFSS's 22.4 dB. This substantial increase demonstrates the proposed method's superior capability in handling low-frequency signals, which are often more susceptible to noise interference. Thus, the results highlight the effectiveness of the proposed method in enhancing the performance of both radar and sonar systems, providing clearer and more reliable signal reception.

Table.3. Bandwidth Utilization

Frequency Range	Method	BU (%)
1 GHz - 10 GHz	FDTD	68
	HFSS	72
	MoM	70
	CST Microwave Studio	71
	Proposed Method	**85**
1 kHz - 100 kHz	FDTD	65
	HFSS	69
	MoM	66
	CST Microwave Studio	68
	Proposed Method	**80**

The proposed method exhibits a remarkable improvement in Bandwidth Utilization (BU) compared to existing methods across both radar and sonar frequency ranges. For radar applications within the 1 GHz to 10 GHz range, the proposed method achieves a BU of 85%, significantly higher than the maximum of 72% attained by HFSS. This indicates that the proposed method effectively leverages the available bandwidth, resulting in enhanced signal processing capabilities and a greater capacity for transmitting more information within the same frequency spectrum. In the sonar frequency range of 1 kHz to 100 kHz, the proposed method also shows a superior BU of 80%, compared to HFSS's 69%. This improvement suggests that the proposed method is more efficient in utilizing the low-frequency spectrum, which is often constrained due to environmental noise and other factors. Thus, the increased bandwidth utilization highlights the proposed method's ability to optimize performance in both radar and sonar systems, allowing for better signal integrity and transmission efficiency, which are crucial for effective target detection and monitoring in various applications.

Table.4. Detection Accuracy

Frequency Range	Method	DA (%)
1 GHz - 10 GHz	FDTD	78
	HFSS	82
	MoM	80
	CST Microwave Studio	81
	Proposed Method	**90**
1 kHz - 100 kHz	FDTD	75
	HFSS	79
	MoM	76
	CST Microwave Studio	78
	Proposed Method	**88**

The proposed method demonstrates a substantial enhancement in Detection Accuracy (DA) across both radar and sonar frequency ranges. For radar applications in the 1 GHz to 10 GHz range, the proposed method achieves a DA of 90%, outperforming existing methods, with HFSS having the highest accuracy at 82%. This increase indicates that the proposed method is highly effective in identifying and distinguishing targets, crucial for operational effectiveness in radar systems. In the sonar frequency range of 1 kHz to 100 kHz, the proposed method also excels, achieving a DA of 88% compared to HFSS's 79%. This significant improvement highlights the proposed method's capability in detecting low-frequency signals, which often face challenges from environmental noise and interference. The enhanced detection accuracy indicates a greater reliability in target identification, leading to improved decision-making in applications such as underwater navigation and surveillance. Thus, these results affirm the effectiveness of the proposed method in advancing detection capabilities in both radar and sonar systems.

Table.5. Computational Efficiency

Frequency Range	Method	DA (%)
1 GHz - 10 GHz	FDTD	78
	HFSS	82
	MoM	80
	CST Microwave Studio	81
	Proposed Method	**90**
1 kHz - 100 kHz	FDTD	75
	HFSS	79
	MoM	76
	CST Microwave Studio	78
	Proposed Method	**88**

The proposed method exhibits a significant improvement in Computational Efficiency (CE) across both radar and sonar frequency ranges. For radar applications spanning 1 GHz to 10 GHz, the proposed method achieves a CE of 200 iterations per second, notably higher than the existing methods, with HFSS at 130 iterations per second being the closest competitor. This improvement suggests that the proposed method is more effective in optimizing computational resources, enabling faster simulations and quicker results for radar signal processing. In the sonar frequency range of 1 kHz to 100 kHz, the proposed method also outperforms existing approaches with a CE of 180 iterations per second, compared to HFSS's 115 iterations per second. The enhanced computational efficiency means that the proposed method can handle more complex scenarios and larger datasets with less computational burden, which is vital for real-time processing in sonar applications. Thus, these results underscore the proposed method's capability to enhance both speed and performance in radar and sonar systems, leading to better operational efficiency and effectiveness.

6. CONCLUSIONS

The proposed method for enhancing radar and sonar systems demonstrates significant advancements in key performance metrics, including Signal-to-Noise Ratio (SNR), Bandwidth Utilization (BU), Detection Accuracy (DA), and Computational Efficiency (CE). The results indicate that the proposed approach outperforms existing methods—such as FDTD, HFSS, Method of Moments (MoM), and CST Microwave Studio)—across both radar (1 GHz to 10 GHz) and sonar (1 kHz to 100 kHz) frequency ranges. The improvements in SNR and DA highlight the proposed method's superior capability in effectively filtering noise and accurately detecting signals, which are critical for successful target identification and tracking in challenging environments. Furthermore, the enhanced bandwidth utilization ensures that the systems can operate more efficiently, allowing for greater data throughput without sacrificing signal integrity. The increased computational efficiency signifies that the proposed method can execute simulations more rapidly, facilitating real-time processing capabilities essential for modern radar and sonar applications. Thus, these advancements position the proposed method as a robust solution for enhancing the performance of radar and sonar systems, paving the way for more effective and reliable applications in diverse fields, including defense, navigation, and environmental monitoring.

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