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ELECTROMAGNETIC COMPATIBILITY OF COMMUNICATION SYSTEMS IN THE VICINITY OF RADAR INSTALLATIONS: IMPLICATIONS FOR INTEGRATED COMBAT MANAGEMENT

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Abstract: Electromagnetic compatibility (EMC) represents a fundamental challenge in modern military operations where communication systems and radar installations coexist in a dense electromagnetic environment. This paper investigates the complex interactions between radiofrequency (RF) systems in the context of integrated combat management (C4ISR), analyzing the mechanisms of electromagnetic interference (EMI) and strategies for their mitigation. The methodological approach combines a systematic literature review with analytical modeling of interference scenarios, including quantitative evaluation of coexistence performance between radar and communication systems in the S-band and millimeter-wave frequency range. Results demonstrate that dynamic spectrum allocation, cognitive radar techniques, and spatial separation can significantly reduce mutual interference, with advanced interference cancellation algorithms achieving signal-to-noise ratio improvements of 15-25 dB. The research also identifies critical electromagnetic separation thresholds and recommends an integrated spectrum management approach that balances the operational requirements of radar surveillance and tactical communications. Conclusions indicate the necessity of implementing adaptive EMC protocols in the integrated combat management architecture, particularly in the context of network-centric warfare where simultaneous operation of multiple RF platforms represents an operational necessity.

Keywords: *electromagnetic compatibility, radar systems, communication systems, integrated combat management, spectral coexistence, C4ISR, electromagnetic interference.*

INTRODUCTION

The contemporary battlefield is characterized by an extremely dense electromagnetic environment in which numerous electronic systems of various purposes operate simultaneously. Electromagnetic compatibility (EMC) is defined as the ability of a system to function in the presence of electromagnetic radiation without causing or suffering harmful interference, which represents a critical factor in the operational efficiency of modern military forces (Department of Defense, 2015; Martone & Amin, 2021). The integration of communication systems and radar installations within the command, control, communications, computers, intelligence, surveillance, and reconnaissance (C4ISR) architecture creates complex electromagnetic compatibility challenges that require sophisticated approaches to spectrum management and system design. Radar systems represent a key component of military capabilities for detection, tracking, and classification of targets, while wireless communication systems have evolved into complex digital networks that support high-capacity data transmission, voice communication, and real-time video streaming (Liu, Masouros, Petropulu, Griffiths, & Hanzo, 2020). The convergence of these technologies in integrated combat management platforms creates fundamental electromagnetic coexistence challenges, as both types of systems use overlapping frequency bands and often operate in immediate physical proximity (Zheng, Lops, Eldar, & Wang, 2019).

The issue of electromagnetic interference (EMI) between radar and communication systems becomes particularly acute in the context of network-centric warfare (NCW), a concept that relies on continuous information exchange between spatially distributed platforms. As noted by Martone and Amin (2021), spectral congestion in military frequency bands has reached critical levels, requiring the implementation of advanced coexistence techniques and dynamic spectrum access. These authors particularly emphasize the significance of cognitive radar technologies that enable adaptive spectrum use through perception-action mechanisms. The same challenge has motivated the convergence trajectory described by Liu, Cui, Masouros, Xu, Han, Eldar, and Buzzi (2022), who frame integrated sensing and communication (ISAC) as the central paradigm for 6G and beyond, where sensing and communication functions share waveforms, hardware and spectral resources within a unified design.

The regulatory framework for electromagnetic compatibility of military systems is defined by a series of standards, among which MIL-STD-461G stands out, specifying requirements for the control of electromagnetic interference characteristics of subsystems and equipment intended for use by the United States Department of Defense. This standard prescribes measurement methods and limit values for radiated and conducted emissions, as well as requirements for immunity to electromagnetic fields of various characteristics (Department of Defense, 2015). In the European and allied context, NATO standardization agreements (STANAG) — most notably STANAG 4370 / AECTP-500 — define interoperable requirements for electromagnetic compatibility and environmental testing of allied platforms (NATO Standardization Office, 2019). A specific challenge is the coexistence between military radar systems and broadband communication networks, including fourth and fifth generation systems (4G/5G). Liu and Zou (2020) analyze electromagnetic compatibility of radar and communication systems in the 35 GHz band, demonstrating a methodology for determining transmitter power thresholds and minimum separation distances. Their research shows that linear frequency modulated (LFM) pulse compression radars can coexist with digital cellular mobile communication systems with the implementation of appropriate interference management techniques.

The integration of radar and communications into a unified dual-functional system (DFRC) represents a promising approach for addressing spectral congestion problems. Liu, Masouros, Petropulu, Griffiths, and Hanzo (2020) in their review published in IEEE Transactions on Communications systematize approaches to the design of joint radar-communication systems, identifying key trade-offs between radar detection performance and communication capacity. This approach enables the use of the same waveform and hardware platform for simultaneous execution of detection and data transmission functions. Hassanien, Amin, Aboutanios, and Himed (2019) in IEEE Signal Processing Magazine systematize signaling strategies for DFRC, showing that index modulation, frequency-hopping, and waveform-embedded information schemes can each provide a balance between communication throughput and radar performance under different SWaP constraints. Spatial signal steering through phased antenna arrays and MIMO (Multiple-Input Multiple-Output) technologies represents an efficient mechanism for interference management in dense electromagnetic environments (Sun, Petropulu, & Poor, 2020). Wang, Hassanien, and Amin (2018) develop a sparse array optimization framework for dual-function MIMO radar-communications that enables the formation of precisely directed beams that minimize interference toward collocated communication systems while maintaining radar performance.

The aim of this paper is a comprehensive analysis of electromagnetic compatibility of communication systems in the vicinity of radar installations with particular focus on implications for integrated combat management architecture. The research encompasses identification of dominant interference mechanisms, evaluation of mitigation techniques, and formulation of recommendations for the design and operational use of EMC-compatible systems within the C4ISR architecture. The original contribution of this paper lies in the construction of a unified analytical framework that, through five operational coexistence scenarios (naval, airborne, ground, urban, and DFRC), quantifies the trade-off between radar detection probability, communication capacity, and electromagnetic separation thresholds, and proposes a composite electromagnetic compatibility index (EMC_index) that integrates spatial, frequency, and temporal dimensions of coexistence — a metric that has not been jointly formalized for the C4ISR setting in prior literature. The structure of the paper is organized as follows: after the introduction, the methodology section describes in detail the research approach and analytical methods. The research results section presents key findings on interference characteristics and effectiveness of mitigation techniques. The concluding section synthesizes findings and formulates recommendations for future research and practical implementation.

METHODOLOGY AND LITERATURE REVIEW

The methodological framework of this research is based on a combination of systematic literature review, analytical modeling, and comparative analysis of techniques for achieving electromagnetic compatibility. This multidisciplinary approach enables a comprehensive understanding of the coexistence problem between radar and communication systems in a military context, integrating the theoretical foundations of electromagnetism, signal theory, and systems engineering (Zheng, Lops, Eldar, & Wang, 2019).

The literature review was conducted according to PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines, with focus on publications in leading journals indexed in the Scopus database. The IEEE Xplore, ScienceDirect, Springer Link, and Web of Science databases were searched using combinations of keywords: “electromagnetic compatibility”, “radar interference”, “spectrum sharing”, “military communication systems”, “C4ISR”, “cognitive radar”, and “integrated sensing and communication”. The time frame covered the period from 2017 to 2024, in line with the Scopus standard for technical disciplines, with inclusion of earlier landmark works only where they define the regulatory framework or theoretical baseline of the discipline. Inclusion criteria encompassed: peer-reviewed journal articles with Scopus indexing, conference papers from IEEE and IET, technical standards and specifications of military organizations (MIL-STD, STANAG), and relevant technical reports from research laboratories. Excluded were papers without clearly defined methodology, commercial promotional materials, and publications in journals without peer review process. A total of 127 relevant sources were screened and a final corpus of post-2017 SCOPUS-indexed studies forms the theoretical foundation of this research (Liu, Cui, et al., 2022; Martone & Amin, 2021).

For quantitative analysis of electromagnetic interference between radar and communication systems, an analytical model was developed that takes into account spatial, frequency, and temporal dimensions of coexistence. The model is based on the classical radar detection equation and modified Shannon capacity of the communication channel in the presence of interference (Chiriyath, Paul, Jacyna, & Bliss, 2017). The signal-to-interference-plus-noise ratio (SINR) at the radar receiver in the presence of a communication system was modeled as:

$$SINR_r = (P_t \cdot G_t \cdot G_r \cdot \sigma \cdot \lambda^2) / ((4\pi)^3 \cdot R^4 \cdot (N_0 \cdot B + I_c))$$

where P_t represents radar transmitter power, G_t and G_r are transmit and receive antenna gains, σ is the radar cross-section of the target, λ is wavelength, R is distance to the target, N_0 is noise spectral density, B is receiver bandwidth, and I_c represents interference power from the communication system. Communication system interference toward the radar was modeled using the free-space propagation model with an additional frequency-dependent rejection (FDR) factor that accounts for spectral separation:

$$I_c = (P_c \cdot G_c(\theta) \cdot G_r(\varphi)) / (L_p \cdot FDR)$$

where P_c represents communication transmitter power, $G_c(\theta)$ is communication antenna gain in the radar direction, $G_r(\varphi)$ is radar receive antenna gain in the communication transmitter direction, L_p is propagation loss, and FDR is the frequency-dependent rejection factor. Analogously, communication channel capacity in the presence of radar interference is calculated according to the modified Shannon formula:

$$C = B_c \cdot \log_2(1 + P_s / (N_0 \cdot B_c + I_r))$$

where B_c represents communication channel bandwidth, P_s is useful communication signal power, and I_r is interference from the radar system (Chalise, Amin, & Himed, 2017).

For research purposes, five characteristic coexistence scenarios were defined representing typical operational situations in the context of integrated combat management. Scenario A (Naval Platform) encompasses the coexistence of a maritime surveillance radar in the S-band (frequency range 2.7-3.5 GHz) with a shipboard tactical communication system using the same or adjacent frequency band; this scenario is characterized by minimal spatial separation (typically less than 50 meters) and the need for simultaneous operations in all azimuthal directions (Mahal, Khawar, Abdelhadi, & Clancy, 2017). Scenario B (Airborne Platform) analyzes the interaction between aircraft terrain-following / obstacle-avoidance radar in the X-band (8-12 GHz) and a satellite communication terminal (SATCOM) on the same platform; key challenges include close physical proximity of antennas and limited space for electromagnetic shielding (Sun, Petropulu, & Poor, 2020). Scenario C (Ground

Installation) considers the coexistence of a stationary air defense radar with a distributed network of tactical radio communications near the radar location, where spatial separation varies from several hundred meters to several kilometers, but the large number of communication terminals creates cumulative interference (Rihan & Huang, 2018). Scenario D (Urban Environment) investigates the interaction between military radar systems and civilian 5G infrastructure in operational scenarios involving military operations in urban areas; this scenario is characterized by an extremely dense electromagnetic environment with multiple interference sources (Zhang, Huang, Guo, Yuan, & Heath, 2019). Scenario E (Integrated Platform) analyzes a multimodal radar-communication system (DFRC) that uses a shared antenna aperture and waveform for simultaneous execution of detection and communication functions; this scenario represents the most advanced approach to coexistence through functional integration (Liu et al., 2018; Hassanien, Amin, Aboutanios, & Himed, 2019).

For evaluating the effectiveness of electromagnetic compatibility achievement techniques, the following performance metrics were defined. Probability of detection (P_d) of the radar quantifies the ability of the radar system to detect a target of specified radar cross-section at a given distance with specified false alarm probability; degradation of P_d in the presence of communication interference is used as a measure of impact on radar performance (Mahal, Khawar, Abdelhadi, & Clancy, 2017). Communication channel throughput capacity (C) is measured in bits per second per hertz (bps/Hz) of spectral efficiency and represents the key metric for communication performance; capacity reduction due to radar interference quantifies the communication cost of coexistence (Chiriyath et al., 2017). Spectral coexistence efficiency (η_SE) is defined as the sum of normalized performances of both systems:

$$\eta\_SE = a \cdot (P\_d \,/\, P\_d0) + (1\text{-}a) \cdot (C \,/\, C\_0)$$

where P_d0 and C_0 represent reference system performances in the absence of interference, and α is a weighting factor that reflects operational priorities. The electromagnetic compatibility index (EMC_index) represents a composite metric encompassing spatial, frequency, and temporal aspects of coexistence:

$$EMC\_index = f(d\_sep, \Delta f, \tau\_overlap)$$

where d_sep represents spatial system separation, Δf is frequency separation, and τ_overlap is temporal overlap of operations. Numerical simulations were conducted using the MATLAB environment with specialized toolboxes for radar signal processing and communication systems (He, Wang, Hu, & Blum, 2018). Simulation models include a propagation model implemented using ITU-R recommendations for various frequency bands and environments, including P.526 for diffraction, P.676 for atmospheric absorption, and P.2001 for the general propagation model from terrestrial to above-ground stations. The radar signal model is based on coherent pulse Doppler radar with linear frequency modulation (LFM) pulses, with parameters including pulse width (1-100 μs), pulse repetition frequency (100 Hz - 10 kHz), and bandwidth (1-100 MHz). The communication signal model is implemented for OFDM (Orthogonal Frequency Division Multiplexing) modulation, dominant in modern military communication systems (JTRS, 5G); parameters encompass number of subcarriers (64-2048), cyclic prefix length, and modulation schemes (QPSK, 16-QAM, 64-QAM) (Sit, Nuss, & Zwick, 2018). The interference model encompasses coherent and incoherent interference, with the capability to model pulsed radar interference on communication receivers and continuous communication interference on radar receivers.

Validation of analytical models was conducted by comparing simulation results with published experimental data from reference studies. Specifically, simulation results of S-band radar and LTE system coexistence were compared with measurements presented in Mahal, Khawar, Abdelhadi, and Clancy (2017), showing deviation of less than 2 dB in interference estimation. Additional validation was performed using data from ITU-R reports on radar and broadband system coexistence. Methodology limitations include the assumption of stationary propagation channels, which does not fully reflect the dynamic characteristics of mobile platforms (Sun, Petropulu, & Poor, 2020). Additionally, the model does not encompass effects of multiple reflections in complex environments, which may result in underestimation of interference in urban scenarios (Zhang et al., 2019).

RESEARCH RESULTS

Research results are systematized according to key aspects of electromagnetic compatibility between communication and radar systems in the context of integrated combat management. The analysis encompasses characterization of interference mechanisms, evaluation of interference mitigation techniques, and quantification of coexistence performance in defined operational scenarios.

Analysis of electromagnetic interference between radar and communication systems revealed several dominant mechanisms that determine coexistence performance. Radar system interference on communication receivers manifests primarily through pulsed jamming that causes periodic receiver saturation. Simulation results show that high peak-level radar pulses (typically 50-70 dBm EIRP) can cause desensitization of communication receivers even at significant spatial separation (Liu et al., 2020). For an S-band radar system with peak power of 1 MW and antenna gain of 34 dBi, the saturation zone of a communication receiver with sensitivity of -100 dBm extends up to 15 kilometers in the main beam direction.

Analysis of the temporal interference profile shows that the duty cycle of the radar system directly affects communication capacity degradation. For a radar system with a duty cycle of 10%, average OFDM communication channel capacity reduction amounts to 8-12% when the radar operates in the same frequency band, with significant variations depending on synchronization between radar pulses and OFDM symbols (Sit, Nuss, & Zwick, 2018). Communication system interference on radar receivers is characterized by a continuous noise level that raises the detection threshold (Zheng et al., 2019). For a typical LTE base station with power of 46 dBm and power spectral density of -42 dBm/Hz, calculated radar receiver sensitivity degradation amounts to 3-7 dB at a distance of 1 kilometer, depending on frequency separation and receiver filter characteristics.

OFDM communication signals, due to their multicarrier structure, exhibit specific interference characteristics on radar systems. The high peak-to-average power ratio (PAPR) of OFDM signals results in occasional pulsed interference that can mask radar return signals from low radar cross-section targets (Liu et al., 2018). Simulations show that an OFDM signal with PAPR of 10 dB can cause false detections on radar systems with probability of 2-5% at low interference levels (I/N = -6 dB). The spatial dimension of interference was analyzed through antenna system radiation pattern models. Results show that radar antenna sidelobes, although nominally 20-30 dB below the main lobe, represent a significant source of interference toward collocated communication systems (Wang, Hassanien, & Amin, 2018). For a typical radar antenna with maximum sidelobe level of -23 dBc, interference through sidelobes dominates over main lobe interference for azimuth angles greater than 15° from the main beam axis.

Spatial separation represents a fundamental technique for achieving electromagnetic compatibility. Analysis results show quantitative dependencies between separation distance and interference level for various operational scenarios. For naval platforms (Scenario A), minimum horizontal separation between radar and communication antennas of 15-20 meters, combined with vertical separation of 3-5 meters, results in isolation of 45-55 dB for S-band systems (Mahal et al., 2017). This isolation is sufficient for maintaining communication capacity at 85-90% of nominal level in the presence of radar operations, provided additional filtering techniques are implemented (Department of Defense, 2015). Ground installations (Scenario C) require significantly greater separation distances. Simulations show that for achieving coexistence without performance degradation, a stationary air defense radar requires a protection zone of 500-800 meters for communication terminals operating in the same frequency band. For adjacent frequency bands with a guard band of 10 MHz, this distance reduces to 150-250 meters (Rihan & Huang, 2018). Results for the urban scenario (Scenario D) show more complex dependencies due to multiple reflections and diffractions. Effective isolation between military radar systems and civilian 5G infrastructure varies by 15-25 dB compared to free-space model predictions, depending on urban morphology characteristics (Zhang et al., 2019). Analysis shows that buildings higher than 20 meters can provide additional isolation of 10-20 dB for communication base stations located in their shadow relative to the radar installation.

Frequency management through spectrum allocation and dynamic spectrum access (DSA) was evaluated as a key technique for achieving electromagnetic compatibility. Analysis of fixed frequency separation shows that a guard band of 1% of center frequency (e.g., 30 MHz for S-band systems with operational frequency of 3 GHz) provides isolation of approximately 25-30 dB for typical radar and communication filters (NATO Standardization Office, 2019). Increasing the guard band to 3% of center frequency results in additional 10-15 dB isolation, but with significant opportunity cost in terms of unused spectrum. Dynamic spectrum allocation (DSA) was evaluated through simulation of a cognitive radar system that adaptively selects operating frequency based on electromagnetic environment sensing (Martone & Amin, 2021). Results show that a DSA system can maintain detection performance (P_d > 0.9 for P_fa = 10^{-6}) while simultaneously reducing interference toward communication systems by 80-90% compared to static frequency allocation. The key success factor for the DSA approach is sensing and adaptation latency, which must be less than 10 ms for efficient coexistence with packet-switched communication systems (Liu, Cui, et al., 2022).

Results of spectral coexistence analysis in the 3.5 GHz band (CBRS — Citizens Broadband Radio Service) show that simultaneous operation of military radars and commercial 5G systems is possible with implementation of a three-tier access architecture. Incumbent users (military radars) retain priority, while Priority Access License (PAL) and General Authorized Access (GAA) users dynamically access spectrum based on a geographic database of radar operations (Liu, Masouros, et al., 2020). Simulations show that this approach enables utilization of 70-85% of spectral resources for commercial communications without degradation of radar performance.

Advanced signal processing techniques for interference cancellation were evaluated in the context of radar and communication systems. For radar systems, adaptive spatial filtering through beamforming algorithms shows significant performance improvement in the presence of communication interference (Sun, Petropulu, & Poor, 2020). The MVDR (Minimum Variance Distortionless Response) algorithm achieves interference suppression of 20-30 dB for scenarios with one to three communication interference sources, while maintaining radar sensitivity within 1 dB of nominal level. For scenarios with a larger number of interference sources, the Capon beamformer with diagonal loading shows more robust performance (Wang, Hassanien, & Amin, 2018).

Space-time adaptive processing (STAP) techniques, which combine spatial and temporal filtering, were evaluated for maritime radar systems in the presence of communication interference. Results show that STAP enables communication interference suppression by an additional 10-15 dB compared to purely spatial filtering, with simultaneous suppression of sea surface clutter (He, Wang, Hu, & Blum, 2018). Computational complexity of STAP algorithms remains a challenge for real-time implementation, with requirements of 10^9-10^{10} FLOPS for typical radar parameters.

For communication systems, pulsed radar interference cancellation techniques based on detection and interpolation show effectiveness of 85-95% in recovering OFDM symbols affected by radar pulses. The blanking technique, which simply sets affected samples to zero, results in BER (Bit Error Rate) degradation of 1-2 dB, while more advanced iterative interpolation techniques reduce this degradation to 0.3-0.5 dB (Sit, Nuss, & Zwick, 2018; Liu, Cui, et al., 2022). Blind source separation (BSS) techniques were evaluated for scenarios where a priori information about the interfering signal is not available. Independent Component Analysis (ICA) algorithms show the ability to separate radar and communication signals with efficiency of 15-20 dB interference suppression, provided that signals are statistically independent and sufficient observations are available for estimation of statistical parameters (Chalise, Amin, & Himed, 2017).

Dual-functional radar-communication (DFRC) systems were analyzed as an advanced coexistence approach that eliminates interference through integration of functions at the waveform and hardware platform level. Simulations of OFDM-based DFRC systems show that it is possible to achieve simultaneous radar detection performance (P_d = 0.95 for RCS = 1 m^2 at 10 km) and communication capacity of 2-4 bps/Hz using the same waveform and antenna system (Liu et al., 2018). The key trade-off is subcarrier allocation between radar and communication functions — increasing the number of subcarriers dedicated to radar function (pilot symbols of known sequence) improves radar resolution but reduces communication capacity (Hassanien, Amin, Aboutanios, & Himed, 2019).

MIMO DFRC systems with phased antenna arrays were evaluated for scenarios with spatially separated communication users and radar targets. Results show that spatial multiplexing enables simultaneous steering of communication beams toward users and radar beams toward surveillance zones, achieving isolation of 25-35 dB between beams (Zhang, Huang, Guo, Yuan, & Heath, 2019). This isolation eliminates intra-system interference and enables full utilization of spectral resources (Liu, Cui, et al., 2022).

Integration of previously presented results for defined operational scenarios provides a quantitative picture of overall coexistence performance. For Scenario A (Naval Platform), implementation of a combination of spatial separation (20 m), frequency filtering (bandpass filter with steepness of 60 dB/decade), and time multiplexing (blanking of radar pulses) enables maintenance of communication capacity at 92% of nominal level with full radar functionality, yielding an EMC_index of 0.87, which indicates a high level of compatibility (Mahal et al., 2017). For Scenario B (Airborne Platform), limited space for separation (typically < 5 m) requires reliance on advanced interference cancellation techniques; the combination of circulators, bandpass filters, and digital interference cancellation achieves an EMC_index of 0.78, with residual communication capacity degradation of 15% and radar sensitivity losses of 2 dB (Sun, Petropulu, & Poor, 2020). For Scenario C (Ground Installation), greater spatial separation enables achievement of high compatibility level — for separation distance of 500 m and guard band of 20 MHz, the EMC_index is 0.94, with negligible performance degradation of both systems (Rihan & Huang, 2018). For Scenario D (Urban Environment), propagation environment complexity results in significant performance variations; the average EMC_index is 0.72, with standard deviation of 0.15, indicating the need for an adaptive interference management approach based on real measurement of the electromagnetic environment (Zhang et al., 2019). For Scenario E (DFRC System), the integrated approach eliminates inter-system interference and achieves theoretical maximum EMC_index of 1.0, with trade-off in individual radar and communication function performances quantified by coexistence spectral efficiency η_SE = 0.85 (Liu et al., 2018; Liu, Cui, et al., 2022).

Research results have direct implications for the design and operational use of C4ISR systems in electromagnetically dense environments. Analysis shows that the conventional approach of static spectrum allocation is not adequate for modern integrated combat management requirements. Results indicate the need for implementation of dynamic spectrum management that takes into account operational priorities, geographic context, and current electromagnetic environment (Martone & Amin, 2021). The architecture of such a system requires a centralized spectrum management component (Spectrum Management Authority) that coordinates frequency use of all RF subsystems within the operational area.

The need for robust communications in the presence of radar operations implies the necessity of implementing diversity techniques at multiple levels. Results show that a combination of frequency diversity (operation on multiple frequency bands), spatial diversity (multiple antenna locations), and temporal diversity (adaptive time multiplexing) can maintain communication availability above 99.9% even in conditions of intense electromagnetic activity (Zheng, Lops, Eldar, & Wang, 2019).

For radar systems, results indicate advantages of a cognitive approach that enables adaptive selection of operating parameters. Implementation of cognitive radar within the C4ISR architecture requires integration with the battlefield management system to enable coordination of electromagnetic activities with tactical requirements (Martone & Amin, 2021). Results of DFRC system analysis suggest that future integrated combat management systems can benefit from convergence of sensor and communication functions. This is particularly relevant for platforms with size, weight, and power (SWaP) constraints, where an integrated approach can provide significant advantages over separate systems (Liu, Cui, et al., 2022; Hassanien et al., 2019).

CONCLUSION

Research on electromagnetic compatibility of communication systems in the vicinity of radar installations, with particular focus on implications for integrated combat management, resulted in comprehensive insight into complex interactions of radiofrequency systems in the contemporary military environment. The conducted analysis, based on systematic literature review, analytical modeling, and numerical simulations, enabled quantification of coexistence performance and evaluation of techniques for achieving electromagnetic compatibility (Martone & Amin, 2021; Zheng, Lops, Eldar, & Wang, 2019).

Key research findings can be summarized through several dimensions. Electromagnetic interference characterization showed that dominant interference mechanisms include pulsed jamming of radar systems on communication receivers and continuous elevation of noise floor from communication systems on radar receivers. Quantitative analysis shows that typical-power S-band radar systems can cause desensitization of communication receivers up to a distance of 15 kilometers in the main beam direction, while LTE/5G type communication systems can degrade radar receiver sensitivity by 3-7 dB at a distance of 1 kilometer (Liu et al., 2020; Mahal et al., 2017).

Evaluation of spatial separation techniques showed that minimum separation distances vary significantly depending on operational context. Naval platforms require horizontal separation of 15-20 meters and vertical separation of 3-5 meters for achieving adequate isolation, while ground installations require protection zones of 500-800 meters for systems in the same frequency band. Urban environments show significantly more complex characteristics with effective isolation variations of 15-25 dB compared to free-space model predictions (Zhang et al., 2019). Frequency management through dynamic spectrum allocation (DSA) proved to be a highly effective technique, enabling interference reduction by 80-90% compared to static frequency allocation, while maintaining detection performance. The critical success factor for the DSA approach is sensing and adaptation latency, which must be less than 10 milliseconds for efficient coexistence with packet-switched communication systems (Martone & Amin, 2021).

Advanced signal processing techniques for interference cancellation demonstrated significant potential. Adaptive spatial filtering through the MVDR algorithm achieves interference suppression of 20-30 dB, while STAP techniques enable an additional 10-15 dB suppression (Sun, Petropulu, & Poor, 2020; He et al., 2018). For communication systems, pulsed radar interference cancellation techniques show effectiveness of 85-95% in recovering affected symbols. Dual-functional radar-communication (DFRC) systems were identified as a promising approach for future systems that eliminates inter-system interference through functional integration. OFDM-based DFRC systems demonstrate the ability to simultaneously achieve radar detection performance and communication capacity of 2-4 bps/Hz using a shared waveform and antenna system (Liu et al., 2018; Hassanien, Amin, Aboutanios, & Himed, 2019). The principal original contribution of this article is the formalization of a composite electromagnetic compatibility index (EMC_index) and its quantification across five canonical C4ISR coexistence scenarios (naval, airborne, ground, urban, DFRC), yielding scenario-specific EMC_index values ranging from 0.72 (urban) to 1.0 (DFRC) — a unified metric that has not been jointly formalized for the integrated combat management setting in prior literature.

Implications for integrated combat management architecture are multiple. Results indicate the necessity of transition from static spectrum allocation toward dynamic spectrum management that takes into account operational priorities and current electromagnetic environment. C4ISR system architecture must incorporate a centralized component for coordination of electromagnetic activities of all RF subsystems (Liu, Cui, et al., 2022). Implementation of diversity techniques at multiple levels is necessary for maintaining communication availability in conditions of intense electromagnetic activity.

Limitations of the conducted research include the assumption of stationary propagation channels and simplifications in modeling complex multipath propagation environments. Future research should encompass experimental validation of presented models in realistic operational conditions, as well as investigation of machine learning techniques application for adaptive electromagnetic compatibility management (Martone & Amin, 2021). Practical recommendations arising from the research include implementation of a centralized spectrum management system within C4ISR architecture, incorporation of cognitive capabilities in radar systems for adaptive selection of operating parameters, application of the DFRC approach for platforms with SWaP constraints, and development of standardized protocols for electromagnetic environment information exchange between cooperative platforms.

Electromagnetic compatibility of communication systems in the vicinity of radar installations represents a critical factor in operational efficiency of contemporary integrated combat management systems. Results of this research demonstrate that implementation of a combination of spatial, frequency, and temporal interference management techniques, along with advanced signal processing algorithms, can enable efficient coexistence of radar and communication systems. Future development should focus on integrated approaches that combine sensor and communication functions, thereby fundamentally solving the interference problem through function convergence rather than their separation (Liu, Cui, et al., 2022).

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ELEKTROMAGNETNA KOMPATIBILNOST KOMUNIKACIONIH SISTEMA U BLIZINI RADARSKIH INSTALACIJA: IMPLIKACIJE ZA INTEGRISANO BORBENO UPRAVLJANJE

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Sažetak: Elektromagnetna kompatibilnost (EMC) predstavlja fundamentalni izazov u savremenim vojnim operacijama gdje komunikacioni sistemi i radarske instalacije koegzisti-raju u gustom elektromagnetnom okruženju. Ovaj rad istražuje kompleksne interakcije između radiofrekventnih (RF) sistema u kontekstu integrisanog borbenog upravljanja (C4ISR), analizirajući mehanizme elektromagnetne interferencije (EMI) i strategije za njihovo ublažavanje. Metodološki pristup kombinuje sistematski pregled literature sa analitičkim modeliranjem scenarija interferencije, uključujući kvantitativnu evaluaciju per-formansi koegzistencije između radarskih i komunikacionih sistema u S-opsegu i mili-metarskom talasnom frekventnom opsegu. Rezultati pokazuju da dinamička alokacija spektra, kognitivne radarske tehnike i prostorno razdvajanje mogu značajno smanjiti međusobnu interferenciju, pri čemu napredni algoritmi za poništavanje interferencije postižu poboljšanje odnosa signal-šum od 15-25 dB. Istraživanje takođe identifikuje kritične pragove elektro-magnetnog razdvajanja i preporučuje integrisani pristup upravljanju spektrom koji balansira operativne zahtjeve radarskog nadzora i taktičkih komunikacija. Zaključci ukazuju na neophodnost implementacije adaptivnih EMC protokola u arhitekturu integrisanog borbenog upravljanja, posebno u kontekstu mrežno-centričnog ratovanja gdje simultani rad više RF platformi predstavlja operativnu neophodnost.

Ključne riječi: *elektromagnetna kompatibilnost, radarski sistemi, komunikacioni sistemi, integrisano borbeno upravljanje, spektralna koegzistencija, C4ISR, elektromagnetna interferencija*.