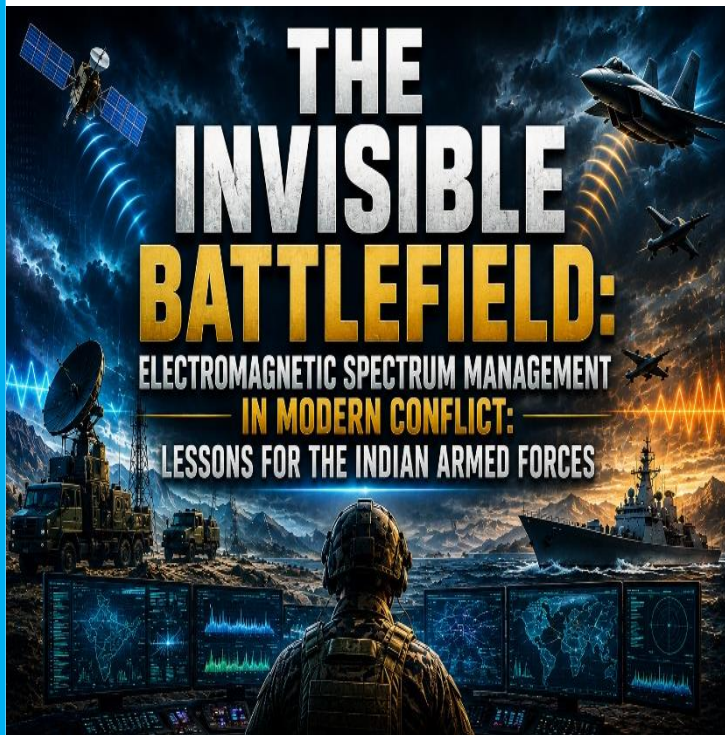




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About the Occasional Paper

This Occasional Paper examines the growing importance of electromagnetic spectrum management as a decisive enabler of contemporary military operations. Drawing on lessons from recent conflicts and evolving military doctrines, it analyses how modern militaries are competing for electromagnetic superiority and adapting to increasingly contested spectrum environments. The paper argues that India faces two fundamentally different electromagnetic challenges, a densely populated, co-located spectrum environment along its western borders and a high altitude, infrastructure constrained and space dependent environment along its northern borders. It concludes with recommendations for strengthening India's electromagnetic spectrum operations, resilience and warfighting effectiveness.

**THE INVISIBLE BATTLEFIELD:
ELECTROMAGNETIC SPECTRUM MANAGEMENT
IN MODERN CONFLICT:
LESSONS FOR THE INDIAN ARMED FORCES**

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Introduction: The Spectrum as a Warfighting Domain

Every modern military capability depends upon access to the Electromagnetic Spectrum (EMS). Radios, radars, satellites, drones, precision guided munitions, navigation systems and command networks all rely upon electromagnetic energy to function. Denial of spectrum access can render technologically advanced forces combat ineffective without a single kinetic strike.

Historically, spectrum management was treated as a technical activity for signals and communications specialists. Recent conflicts have fundamentally altered that perception. The spectrum has become a manoeuvre space, a domain that must be seized, held and exploited just as surely as ground, air or sea.

Russian Electronic Warfare (EW) systems have repeatedly degraded the effectiveness of Global Positioning System (GPS) guided munitions in Ukraine. Israel has demonstrated the capacity to neutralise hostile drones through electromagnetic means alone. The United States (US) has integrated spectrum operations into the opening phase of its broader campaign planning. Along India's western borders, GPS interference incidents have affected both military and civilian activity simultaneously.

These developments emphasise towards toward a broader strategic shift. The opening contest in future wars may not be fought with tanks, aircraft or missiles, but in the invisible space of the EMS. For India, operating in one of the world's most demanding electromagnetic environments and with adversaries on two fronts, extreme terrain variation, a dense civilian spectrum footprint and a nuclear overhang, this is not a distant theoretical concern. It is a present operational reality.

Understanding Electromagnetic Spectrum Operations

EMS Operations (EMSO) encompass three interrelated but operationally inseparable activities.

Electronic Warfare. The deliberate use of electromagnetic energy to attack, protect, or exploit systems that depend on the electromagnetic spectrum. It comprises electronic attack (jamming, spoofing, directed energy), electronic protection (frequency hopping, shielding, emissions control) and electronic support (signals intelligence, threat warning, geolocation).

Spectrum Management. The allocation, coordination and deconfliction of frequencies across friendly forces to ensure effective operations, while, minimising mutual interference, is a challenge that

grows exponentially as the density of spectrum dependent platforms increases.

Electromagnetic Battle Management (EMBM).

The real-time orchestration of EMS activities across the joint force, integrating EW effects into operational planning and execution at the tempo of modern combat.

Managing the EMS. A commander conducting electronic attack must simultaneously ensure that the jamming does not degrade friendly communications, blind his own Air Defence (AD) radars, impact on his own drones or disrupt civilian infrastructure which would generate political costs. Managing this challenge at speed, under fire, in terrain that shapes electromagnetic propagation in ways that no flat terrain system specification can predict, is the defining spectrum management problem of the current era.

A Critical Distinction: Co-located and Geographically Separated Spectrum Contests

Geography Shapes the Spectrum. Geography fundamentally shapes the character of electromagnetic warfare. The most important analytical distinction in contemporary spectrum conflict is not between sophisticated and unsophisticated adversaries, but between those who share a physical battlespace and those who do not.

Geographically Separated Adversaries. When opposing forces operate in largely distinct physical environments, as in long range strike campaigns or operations across significant maritime or territorial distances, the electromagnetic environments are relatively separated. The attacking force focuses primarily on penetrating, disrupting or suppressing adversary systems in a spectrum environment it is visiting rather than inhabiting. Spectrum management becomes largely an offensive access problem. Can the force suppress or deceive enemy radars and command networks long enough to accomplish its objectives? The risk of electromagnetic fratricide is manageable, the civilian spillover is limited, the adaptation cycle is measured in campaign timelines rather than tactical hours.

Co-located Adversaries. The situation transforms categorically when adversaries share the same physical battlespace along the India-Pakistan borders and across much of India's northern borders, opposing forces operate within overlapping spectrum environments. This generates challenges with no equivalent in the separated adversary model.

Spectrum Management Challenges. The shared battlespace generates several interrelated spectrum management challenges. These include the risk of electromagnetic fratricide, where jamming adversary

GPS simultaneously degrades friendly systems operating nearby; severe spectrum congestion, as thousands of drones, radios, artillery networks, command systems and civilian communications compete for the same frequency bands; rapid adaptation cycles, with adversaries detecting and countering new frequencies or waveforms within hours rather than weeks; civilian infrastructure exposure, where military EMSO in densely populated theatres can generate significant political and diplomatic consequences that constrain operational freedom. It also faces the challenge of emission discrimination of distinguishing friendly from hostile signals in a congested and highly dynamic electromagnetic environment.

India's Dual Spectrum Challenge. India must be proficient in both models simultaneously. Its western borders present the co-located problem in a densely populated plain, whereas the northern borders present a variant of the co-located problem that existing doctrine, shaped by experience in Ukraine, Gaza and the Gulf, does not adequately address. The reasons are structural and are examined in detail in the succeeding paragraphs.

Lessons from Contemporary Conflicts

US and North Atlantic Treaty Organization (NATO). The US has developed the world's most systematically organised electromagnetic warfare

architecture.¹ Dedicated joint institutions dedicated airborne electronic attack platforms, global intelligence networks integrating signals data from all domains, and the comprehensive electromagnetic threat libraries upon which much of the NATO alliance depends collectively, provide significant operational advantages.² Recent operations suggest that space based electromagnetic warfare has emerged as a decisive enabling capability. This enables strike aircraft to operate in contested airspace by suppressing adversary Satellite Communications (SATCOM) and navigation systems before kinetic assets crossed the border. This integration of space domain EMSO into campaign planning represents a doctrinal evolution that most militaries, including many NATO members, have yet to replicate.³ The alliance's vulnerability, exposed by the Ukraine conflict, is institutional rather than technological. Decades of counterinsurgency focus led European militaries to reduce their EW capabilities and spectrum management expertise to a state of limited operational readiness.⁴ When Russian forces deployed AD systems in previously unobserved modes, NATO's electronic threat libraries were outdated and its airborne electronic attack capacity was concentrated almost entirely in the US assets.⁵ The lesson for India is that electromagnetic superiority cannot be borrowed from elsewhere and

is now required. It must be indigenously developed, maintained and continuously updated.

Russia. Russia's electromagnetic warfare capability reflects a doctrinal inheritance from the Soviet era that was never abandoned, even during the decades when Western militaries pivoted to counterterrorism.⁶ Systems designed for radar suppression, GPS denial across large operational areas and communications disruption at multiple layers, provided significant advantages in the early phases of the Ukraine conflict, most visibly in degrading the effectiveness of Western supplied precision munitions. Yet the conflict also exposed the limitations of a doctrine built for structured, set piece operations. Russian EW systems were optimised for deliberate campaigns against a less technically capable adversary. Against an opponent conducting rapid, decentralised adaptation, shifting frequencies, introducing new platforms and exploiting commercial technology at tactical speed. The Russian strategy of heavy, static, echeloned approach proved brittle. Tactical EW fratricide, where Russian jamming degraded Russian drone operations, was a recurring problem documented by multiple independent observers.

Adaptive Dominance. The broader lesson is that electromagnetic superiority is not a condition that can be established and held. It must be continuously

contested and reestablished. A military that achieves EMS dominance through massed, static capability will lose it to an adversary that adapts faster.

Ukraine.

- Ukraine's electromagnetic adaptation represents one of the most consequential military innovation cycles in recent history.⁷ Faced with Russian jamming that rendered GPS guided systems unreliable, Ukrainian forces did not simply attempt to counter the threat. They systematically eliminated the vulnerabilities it exploited. The progression moved from frequency hopping communications and hardened satellite links, through fibre optic drone command links that bypass radio frequencies entirely, to Artificial Intelligence (AI)-based navigation and target acquisition systems that operate without GPS dependency.⁸ In the later stages of the conflict, the most critical EW innovations were being produced by private companies and startups operating on adaptation cycles of weeks rather than the procurement timelines of years that characterise state defence industries.
- The Ukrainian experience carries three specific lessons for India.⁹ First, resilience through redundancy. Every critical

spectrum dependent system must have a non EMS dependent backup. Second, the primacy of adaptation speed over system sophistication, a less capable system that can be modified in weeks is operationally superior to a more capable system that requires years to update. Third, the value of a defence innovation ecosystem that can operate at the tempo of tactical change.

Israel. Israel's electromagnetic warfare capability reflects the operational demands of continuous multi front conflict and the outputs of a domestic defence industry with significant depth. The integration of EW, intelligence, cyber operations and AI into a coordinated operational framework, rather than treating EW as a specialist supporting function, distinguishes the Israeli model from other comparable militaries. Of operational significance is the demonstrated ability to neutralise drone threats through electromagnetic means, reducing dependence on kinetic interceptors that are finite in number and expensive to replace.¹⁰ In a conflict environment where adversaries can launch hundreds of drones in a single operation, the ability to defeat a significant proportion through spectrum explains that missiles have direct implications for operational sustainability.¹¹ This capability was developed not as a luxury supplement to kinetic AD, but as a necessity

driven by finite interceptor stocks, a resource constraint that forced doctrinal innovation.

The Economics of Spectrum Warfare. The implication for India is that electromagnetic investment should be evaluated not only against the direct cost of EW systems, but also against the cost of the kinetic alternatives they displace or supplement. A spectrum capability that reduces dependence on expensive interceptors, precision munitions or manned aircraft sorties has a force multiplier value that conventional acquisition analysis tends to understate.

China. China's Apr 2024 military reforms marked the most significant restructuring of the People's Liberation Army (PLA) since 2015. The Strategic Support Force was dissolved and its responsibilities redistributed among the newly established Information Support Force (ISF), Aerospace Force and Cyberspace Force, all placed directly under the Central Military Commission. The ISF is intended to serve as the connective tissue of the PLA's informationised and increasingly 'Intelligentised' warfare architecture, integrating communications, command and control networks, data fusion and information support across the joint force. The reorganisation reflects Beijing's assessment that future conflicts will be decided as much by information dominance and network resilience as by

kinetic superiority. In operational terms, the PLA today possesses one of the world's most comprehensive suites of electromagnetic, cyber, space and information warfare capabilities, integrated with the BeiDou navigation system, advanced EW platforms, counter space capabilities and AI enabled decision support systems. For India, the significance of these developments lies not merely in China's growing technical capabilities, but also in the PLA's deliberate effort to fuse cyber, space, EW and information operations into a unified operational framework capable of supporting joint theatre level campaigns. This evolution makes the electromagnetic contest along India's northern borders inseparable from the broader competition for information superiority across the cyber and space domains.

The India-Pakistan Borders: A Uniquely Complex Electromagnetic Battlespace

The India-Pakistan electromagnetic environment presents a combination of challenges without precise parallel in any of the conflicts examined above. Understanding why requires examining several intersecting factors given below:

- **Military Operations Within a Dense Civilian Spectrum Environment.** The Line of Control (LoC) and International Border do not run through empty terrain. They run along or near some of the most

densely populated agricultural and urban corridors in South Asia. GPS jamming conducted for military purposes does not recognise the distinction between a military drone and a civilian aircraft approaching Amritsar or Lahore. Cellular network disruption intended to sever adversary communications degrades the same networks used by hospitals, emergency services and civilian populations on both sides. This is not merely a humanitarian concern, but a military one, because of the political and diplomatic costs of civilian infrastructure disruption constrain the operational freedom of the force conducting EMSO. India must plan its spectrum warfare around this constraint rather than despite it.

• **EMS Effects Beyond the Border Belt.** One dimension that contemporary doctrine inadequately addresses is the depth to which electromagnetic effects penetrate the hinterland. Major air bases at Pathankot, Adampur and Halwara, the naval complex at Mumbai, Karwar and Visakhapatnam, and urban centres like Amritsar that lie within or close to the electromagnetic shadow of the LoC or in dense EM environments, all operate in a spectrum environment that is already being contested. GPS spoofing

incidents reported near Delhi's civil aviation approach corridors demonstrate that EMS interference is not self-contained at the border.¹² Civilian airports, nuclear facilities, space ground stations and dual use communications infrastructure in depth locations present distinct electromagnetic vulnerability profiles. Managing these requires extending EMSO planning beyond the tactical battle zone into a broader electromagnetic security architecture that encompasses the hinterland, including spectrum resilience for critical infrastructure, civilian aviation, and strategic military bases that are increasingly within the reach of adversary EMSO.

- **The Chinese Dimension.** Pakistan's military EW ecosystem is substantially of Chinese origin. This has implications that extend beyond the bilateral India-Pakistan balance. The electromagnetic contest along the LoC provides China with operational data on how its doctrine, systems and waveforms perform against Indian platforms, including some Western origin systems in Indian service. The intelligence value of this proxy electromagnetic contest to Beijing should not be discounted for. The LoC potentially provides China valuable opportunities to

observe the operational performance of Chinese origin systems against Indian platforms. This also implies that the India-Pakistan spectrum contest has a component of India's broader strategic competition with China, rather than as a purely bilateral military problem. This is also a driver for indigenous EW technology development in India, with Defence Research and Development Organisation (DRDO), the public and private sector of India, playing a key role.

- **Navigation with Indian Constellation (NavIC) as a Structural Asymmetry.** India's possession of NavIC, an indigenous regional navigation satellite system, is a strategic electromagnetic asset that remains incompletely operationalised¹³. Unlike Pakistan, which structurally depends on GPS, *Globalnaya Navigatsionnaya Sputnikovaya Sistema* (Global Navigation Satellite System) and Chinese BeiDou for precision navigation, India has a pathway to operating effectively in a GPS denied environment of its own creation. Full integration of NavIC across military platforms would reduce India's dependence on foreign Global Navigation Satellite System architectures and improve resilience in GPS-contested environments. This asymmetry is

significant and grows more significant as precision guided munitions and autonomous systems become more central to operational planning. Accelerating NavIC military operationalisation is not a technical procurement decision. It is a strategic one.

- **The Nuclear Constraint.** Unlike Ukraine, the electromagnetic contest on the India-Pakistan borders occurs within a nuclear deterrence framework. This imposes constraints on how aggressively either side can pursue spectrum dominance, particularly on actions that could be interpreted as preparations for a disarming first strike or that risk escalating a spectrum contest into a broader exchange. Spectrum warfare doctrine for India's western borders must therefore incorporate escalation management as an explicit operational parameter, not merely a political afterthought.

The Himalayan Exception: The Northern Borders as a Structurally Different Problem

The conflicts that have shaped contemporary electromagnetic warfare doctrine, Ukraine, Gaza, Lebanon, the Gulf, all of them share a common geographic feature. They are fought at or near sea level, over relatively open terrain, and within or near developed infrastructure networks. These are not

incidental features. They fundamentally determine how the EMS propagates, how EW systems perform and what spectrum management looks like operationally. India's Line of Actual Control (LAC) with China across Ladakh, the Central Sector, Sikkim and Arunachal Pradesh violate virtually every one of these assumptions. The northern border demands a customised electromagnetic doctrine that no existing conflict provides a direct template for.

Terrain Masking and Line of Sight Constraints.

Electromagnetic propagation at very high frequency and above is substantially line of sight dependent. At altitudes of 4,000 to 5,700 m, with intervening ridgelines, deep glacial valleys and complex terrain masking, the coverage patterns of communications systems and EW equipment, bear no resemblance to their flat terrain specifications. A jamming system with a stated range of 200 kms over Ukrainian steppe may provide effective coverage over a narrow valley corridor in Ladakh, and nothing beyond the next ridgeline. This cuts both ways. The same terrain masking that limits friendly EW coverage also limits adversary jamming. Ridgelines that block friendly communications also block enemy interference, terrain functions as a natural electromagnetic shield with no equivalent in the Ukraine or Gaza theatres. India's spectrum management doctrine for the northern borders must exploit this. The threat is not omnidirectional jamming but point specific denial

through terrain channelling. Conversely, high altitude positions with line-of-sight dominance over valleys and approach routes represent electromagnetic high ground with operational value analogous to physical high ground.

Degraded Performance of Airborne EMS Platforms. Much of the electromagnetic innovation demonstrated in contemporary conflicts depends on platforms that perform reliably at low to moderate altitudes in moderate climatic conditions. Commercially available and many military-grade drones, used extensively for communications relay, EW payload carriage and surveillance in Ukraine and Gaza, would face significant performance degradation above 4,000 m. Reduced air density diminishes rotor lift capacity, subzero temperatures degrade battery performance and motor efficiency, high winds at altitude impose structural and operational constraints that flat terrain specifications do not reflect. Aerostats, increasingly used for persistent surveillance and communications relay at lower altitudes, face equivalent constraints at Himalayan elevations, with extreme wind loads, icing and tethering limitations that effectively preclude their use in many forward positions. The consequence is that the EMS architecture deployable on the LAC is materially different from that available in Punjab or along the LoC. Systems that provide reliable communications relay and EW coverage in

one theatre may be operationally unavailable in another. India's EW force structure must account for this vertical dimension of the spectrum problem, not as an edge case, but as a primary planning parameter.

Structural Dependence on Space Based Communications. When terrain masks ground-based line of sight communications and airborne relay platforms cannot operate reliably at high altitude. The communications architecture becomes satellite dependent by default. Consequently, Indian forces operating along the LAC are more structurally dependent on space-based capabilities than forces in almost any other operational environment. This dependence encompasses SATCOM, satellite-based navigation, and satellite imagery for intelligence, targeting and battle damage assessment. This is both a vulnerability and a doctrinal imperative. China is assessed to possess the capability to contest the space domain, having tested direct ascent anti-satellite weapons, orbital interference systems and ground-based SATCOM jamming. Any degradation of India's space-based communications architecture would fall most heavily on precisely the theatre, at the LAC, where India is most dependent upon it and where terrestrial alternatives are least available. The spectrum management problem on the northern theatre is therefore inseparable from space domain resilience in a way that has no equivalent on the Western border. Hardening SATCOM links,

developing redundant space-based communications pathways and building terrestrial backup communications capable of functioning in degraded space conditions, developing satellite parks in multiple locations along the Northern regions, are not peripheral concerns for the northern border but, they are central to its operational viability.

Infrastructure Constraints and Their Electromagnetic Consequences. India's western borders benefit from better proximity to developed infrastructure, power grids, road networks, maintenance chains, and logistics nodes that support the power requirements and maintenance tempo of sophisticated EW systems. The northern borders, despite significant investment in recent years, remain infrastructure constrained in ways that directly affect spectrum operations. High powered, fixed EW systems require stable electrical power supplies that are difficult to provide at remote forward positions. Extended logistics chains increase the lead time for software updates to EW systems. It is a critical constraint given that the effectiveness of modern EW depends on maintaining current threat libraries and waveform databases against an adversary that continuously adapts. The implication is that the EW posture appropriate to the northern borders must prioritise lighter, more power efficient, more deployable and more software updatable systems over the heavy, infrastructure dependent approach

that characterises more established EW architectures. This is closer to the Ukrainian model of agile, startup driven adaptation than to the structured, fixed installation approach of NATO's European EW architecture. It also argues for prepositioned electronic maintenance and update capability at forward bases, rather than relying on logistics chains that terrain and weather can interrupt.

Two Fronts, Two Different Electromagnetic Problems. The cumulative effect of terrain masking, platform altitude limitations, satellite dependence, and infrastructure constraints is that India's northern border demands a fundamentally different electromagnetic doctrine from its western border. A force structure optimised for spectrum competition against Pakistan along the LoC, for a co-located, densely populated, ground level contest with considerable spill over, cannot assume that the same systems, concepts or training will transfer directly to operations on the LAC against the PLA.

India's Dual EMS Challenge. India's two-front EMS challenge is not a single problem on a larger scale. It comprises two structurally distinct problems that demand different solutions, different equipment, different training pipelines and different operational concepts, yet must be integrated through a single joint electromagnetic architecture that is sufficiently flexible to support both simultaneously. Recognising

this structural duality is the starting point for effective doctrine development.

Recurring Causes of Failure in Electromagnetic Operations

Experience across multiple contemporary conflicts reveals several structural failure modes that recur independently of national context or technological sophistication.

Doctrine Technology Mismatch. Possession of advanced EW systems does not, by itself, guarantee operational effectiveness if doctrine and training have not kept pace. Russia's technically capable but doctrinally rigid EW force provides the clearest recent example of this disconnect. Systems designed for one operational model proved brittle against an adversary operating on a different one.

Deconfliction Paralysis. The legitimate fear of electromagnetic fratricide frequently leads commanders to restrict EW employment at precisely the time it is needed the most. Without real time spectrum management tools and clear deconfliction protocols, the default becomes inaction.

Absence of EMBM. Most militaries lack the dedicated command function to orchestrate spectrum activities across the joint force at operational speed. EW remains a specialist

supporting function rather than an integrated operational capability.

Civil Military Spectrum Friction. Operations in densely populated environments generate civilian consequences such as disrupted aviation, degraded telecommunications, compromised emergency services. These create political costs constraining military freedom of action. This is particularly acute on India's western borders.

Over dependence on Vulnerable Technologies Without Resilient Alternatives. Modern precision warfare is built on GPS, SATCOM and encrypted data networks. Resilience requires the demonstrated ability to operate effectively when these systems are degraded or denied, not merely the theoretical understanding that such conditions may arise.

Terrain-Agnostic Planning. Electromagnetic systems and concepts validated in one terrain type are applied without adaptation to fundamentally different environments. The transfer of EW doctrine developed for flat terrain to high-altitude mountain operations represents the failure mode most specific to India's operational environment.

Implications for the Indian Armed Forces

Establish a Joint EMS Centre. India should develop a dedicated joint level institution responsible for EMBM. With real time spectrum deconfliction

and the integration of EW activities into operational planning. This is not an additional intelligence cell or a signals coordination function. It is a warfighting command capability that must be able to operate at the tempo of modern spectrum competition. It should maintain current electronic threat libraries for both western and northern threat environments, including Chinese origin systems operating through Pakistan and directly on the LAC. This institution must be staffed continuously by dedicated specialists drawn from the army and the air force with the EMS being monitored continuously. Continuous monitoring of the EMS across the country including the hinterland, must be carried out as part of the daily activities of the centre.

Fully Operationalise NavIC Across the Military.

The military operationalisation of NavIC, by integrating it as the primary navigation layer across precision-guided munitions, UAV systems, command networks and logistics platforms, should be treated as a strategic priority rather than as an incremental procurement task. The ability to maintain assured navigation in GPS contested environments through an indigenous constellation, is an asymmetric advantage that grows more valuable as precision navigation becomes more central to all warfighting functions.

Develop Theatre Specific EW Doctrine and Force Structure. India requires distinct electromagnetic doctrine for its western and northern theatres, reflecting the fundamentally different operational environments. Western border doctrine must address the challenges of co-located, high-density civilian spectrum management, Chinese proxy EW systems and the escalation constraints of a nuclear environment. Northern border doctrine must address terrain constrained propagation, altitude-induced platform degradation, satellite-dependent communications and the infrastructure limitations of forward positions along the LAC. A single doctrinal framework applied uniformly to both is inadequate for either.

Invest in Altitude Capable EW Platforms. The performance gap of existing EW platforms at the LAC relevant altitudes should be treated as a high priority capability gap. This includes drone platforms capable of reliable EW payload carriage above 4,500 m, power efficient ground-based EW systems designed for forward deployment without grid power, and alternative communications relay solutions not dependent on platforms that degrade at altitude. The defence innovation ecosystem, through Innovations for Defence Excellence and related frameworks, are well positioned to address some of these requirements at the pace the operational environment demands. DRDO must establish fast

track methods for the prototype to induce transition of altitude capable EW platforms.

Harden Space Based Communications for the Northern Borders. Given the structural dependence of LAC operations on SATCOM, the resilience of India's space based communications architecture against jamming, spoofing and physical interference warrants dedicated investment and doctrinal attention. This includes redundant SATCOM pathways, anti-jamming terminals at forward positions, creation of satellite parks at multiple locations along the Northern borders and terrestrial backup communications capable of maintaining minimum command and control under degraded space conditions. Space domain awareness—the ability to understand the electromagnetic environment in which India's communication satellites operate—must form part of the operational picture at the formation level, rather than being confined to the strategic command level.

Institutionalise Spectrum Literacy Across the Force. Electromagnetic awareness must extend beyond specialist communities. Every commander must understand that his radio is a target, that his GPS guided systems are jammable, and that the spectrum environment he operates in will be actively contested. Professional military education at all levels should incorporate spectrum literacy, not as a mere

technical subject for signals officers, but as an operational subject for commanders. The side that manages the spectrum better at the tactical level, in the terrain and conditions specific to its theatre, will increasingly determine the outcome of engagements whose kinetic phase may be measured in just minutes.

Comparative Summary

This section provides a structured comparison of the EMS operational environments, doctrinal requirements and capability priorities across India's two principal theatres and against key peer and near-peer adversaries examined in this paper.

Western Border (India-Pakistan LoC). The electromagnetic environment is characterised by co-located adversaries operating within a dense, congested spectrum shared with extensive civilian infrastructure, aviation corridors, cellular networks, emergency services. Chinese origin EW systems operating through Pakistan provide Beijing with proxy operational data on Indian platform performance. The nuclear deterrence framework imposes constraints on escalatory EMSO. GPS denial incidents numbering over 465 have already affected both military and civilian systems.¹⁴ EMS effects already demonstrably reach strategic depth targets, with GPS spoofing incidents recorded as far as Delhi's civil aviation corridors, underscoring the need for hinterland electromagnetic resilience as part

of western border doctrine. Doctrinal priority: significantly requires precision EMS deconfliction, NavIC operationalisation, escalation managed electronic attack.

Northern Border (India-China LAC). The electromagnetic environment is structurally different. High-altitude terrain masks and shapes line-of-sight propagation in both directions. Airborne EW and communications relay platforms experience significant performance degradation above 4,500 metres. SATCOM becomes the primary architecture for command, control and data links as an operational necessity, while infrastructure constraints limit power availability and logistical support for heavy EW systems. The PLA operates integrated cyber-EW space capabilities under the ISF. Doctrinal priority is to focus on terrain-exploiting EMS posture, altitude-capable lightweight platforms, SATCOM hardening, redundant terrestrial backup.

Adversary Electromagnetic Operational Postures. Russia demonstrated massed, static EW effectiveness in early conflict phases but proved brittle against rapid adaptation. Ukraine demonstrated that agile, private sector driven adaptation cycles of weeks outperform legacy procurement timelines measured in years. Israel demonstrated the operational value of EMS as a kinetic interceptor substitute, with electromagnetic

neutralisation of drone threats therefore reducing dependence on finite missile stocks. China has systematically integrated EW, cyber, space and information operations under unified joint command, with BeiDou providing GPS-independent precision navigation across all PLA platforms.

India's Structural Advantages. NavIC provides an indigenous GPS-independent navigation constellation—an asymmetric advantage, which Pakistan cannot replicate. India possesses several important strengths, including a growing indigenous EW industrial base led by DRDO and the private sector, extensive operational experience along the western border, and significant recent infrastructure development along the LAC. The institutional challenge now is to translate these advantages into theatre-specific doctrine, well-trained formations and integrated joint command structures capable of operating at the speed and complexity of the modern electromagnetic battlespace.

Conclusion

The EMS has become one of the decisive domains of modern warfare. Contemporary conflicts consistently demonstrate that military effectiveness depends not only on platforms and weapons, but on the ability to communicate, navigate, sense and coordinate within contested electromagnetic environments, and to deny this ability to adversaries.

For India, the challenge is far more demanding than other neighbouring countries. The Indian Armed Forces must prepare simultaneously for two structurally different electromagnetic contests, a co-located, densely populated, nuclear overhung spectrum competition on the western borders, where Chinese EW doctrine is being evaluated, and a high altitude, terrain constrained, space dependent competition on the northern borders, for which no existing conflict provides a direct doctrinal template.

The doctrine, platform specifications, training pipelines and command structures appropriate to Punjab are not the same as those appropriate to Ladakh. Treating them as interchangeable is not an efficiency, it is a vulnerability. The structural differences between the two theatres are not minor variations on a common theme. They are different problems that happen to be managed by the same armed forces.

India possesses the foundational advantage for electromagnetic superiority in both theatres. It comprises an indigenous navigation constellation in NavIC, a growing defence industrial base, increasing EW capability and considerable operational experience from the operations on the Western border. The challenge now is institutional, converting these foundations into theatre-specific doctrine,

trained and equipped formations, and joint command structures capable of functioning at the speed of the modern electromagnetic battlespace.

The invisible battlefield is already active on both fronts. The side that best understands the unique electromagnetic character of its terrain, and fights the battle it actually faces rather than the one for which its doctrine was written—will shape the tempo, transparency and trajectory of future conflict. India must be prepared not merely to operate in this environment, but to dominate it on its own terms.

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- ¹⁴ Ministry of Civil Aviation, Government of India, written reply in the Lok Sabha, 20 Mar 2025 (465 instances of GPS interference and spoofing reported around Amritsar and Jammu, Nov 2023 to Feb 2025), as cited in "Indian Aviation Experts Demand Jamming-Resistant Overhaul as GPS Interference from Pakistan Border Endangers Skies", Indian Defence Research Wing, 5 Nov 2025, accessed 24 May 2026, <https://idrw.org/indian-aviation-experts-demand-jamming-resistant-overhaul-as-gps-interference-from-pakistan-border-endangers-skies/>

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