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Regaining EMS Superiority Through New Technologies

Chairman Langevin, Ranking Member Stefanik, and distinguished members of the committee, thank you for the opportunity to discuss the challenges and opportunities facing U.S. military operations in the electromagnetic spectrum (EMS). The EMS is arguably the most important environment in modern warfare, enabling nearly every sensing or navigation technology U.S. troops use and connecting forces from every domain through radio or laser communications. It is also the most unheralded warfighting space—at least in the U.S. defense community. Although we experience the EMS every day through our smart phones, mobile computers, or vehicle collision avoidance systems, the spectrum cannot be seen or felt like land and cyberspace, resulting in it sometimes being a forgotten domain.

Despite its invisibility, access to the EMS is critical for U.S. forces, who without it could lose the advantages they developed by integrating troops, platforms, and systems from multiple domains in combined-arms warfare over the last century. America's adversaries, from Iranian-based militias to People's Republic of China's (PRC) People's Liberation Army (PLA), understand the U.S. military's dependence on the EMS and have fielded a wide array of sensor and communications countermeasures to contest U.S. spectrum access. Unfortunately, the Department of Defense (DoD) allowed its rivals to catch up during the two decades following the Cold War by failing to invest in new technologies that would be more resilient against enemy jamming and deception or better able to degrade opponents' EMS operations.

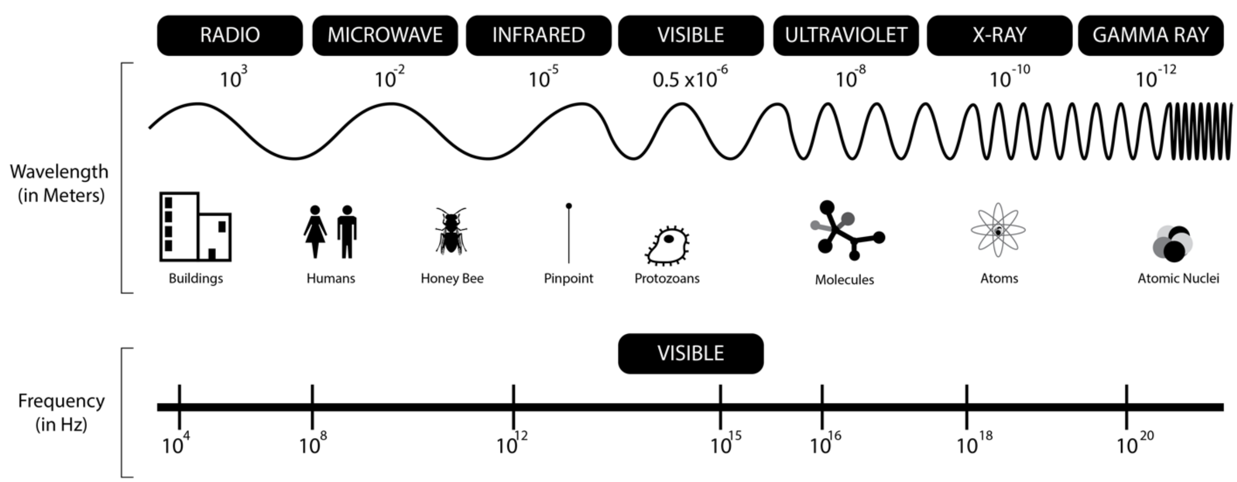
Multiple assessments argue the U.S. military is now behind its adversaries in EMS capabilities.[1] With budgets tightening and the window for regaining an advantage now down to less than a decade against the PRC, it is unlikely the U.S. military will be able to restore EMS superiority by attempting to counter each adversary advancement with a new EMS system or countermeasure.[2] DoD will instead need to pursue new operational concepts and technologies that will allow it to "leap ahead" of its competitors and create enduring advantages in EMS operations.

The U.S. Congress implemented several changes to DoD EMS governance during the last several years, which have not yielded substantial improvements in the U.S. military's ability to gain EMS superiority.[3] At the same time, the Federal Communications Commission has apportioned a more of the EMS to commercial users, constraining military EMS access. Rather than pursue further governance and process changes or resist commercial EMS innovation, the Congress should now focus its attention on ensuring DoD prioritizes the technologies that would enable it to better share the spectrum with civilian users and give the U.S. military an edge in the EMS competition with adversaries, as detailed below.

A congested, constrained, and contested environment

U.S. military doctrine organizes EMS activities into communications, sensing, and electromagnetic spectrum operations (EMSO). Communication and sensing systems such as radios and radar in the radiofrequency (RF) portion of the EMS are widely familiar to civilian and military users. EMS systems are now evolving to send signals using lasers in the higher-frequency infrared (IR) and ultraviolet (UV) ranges that can be detected by semiconductor-based focal plane arrays. Future capabilities are likely to incorporate X-ray and gamma ray emitters and sensors. Figure 1 illustrates the bands of the EMS.

Figure 1: The electromagnetic spectrum



Source: Wikimedia Commons

Similar to sea or air control operations, EMSO activities are intended to control the EMS by exploiting enemy emissions, attacking enemy and protecting friendly forces, and managing spectrum use by military forces. In addition to spectrum management to coordinate and deconflict civilian and military EMS activities, EMSO includes electromagnetic warfare (EW), which comprises three main categories of capabilities and activities:

- Electromagnetic attack (EA) involves the use of electromagnetic energy, directed energy like lasers or high-power microwave, or anti-radiation weapons to attack personnel, facilities, or equipment and is considered a form of fires.

- Electromagnetic protection (EP) refers to actions taken to protect personnel, facilities, and equipment from the effects of friendly, neutral, or enemy use of the EMS. EP is a very broad and important category that includes capabilities to avoid detection like stealth and passive or multistatic sensors as well as capabilities to defeat jamming such as frequency hopping or the use of spot beams by radars or radios.

- Electromagnetic support (ES) includes actions to search for, intercept, identify, and locate or localize sources of intentional and unintentional radiated EM energy. Although ES activities can support signals intelligence (SIGINT), ES is considered an operational activity to support commanders in controlling the EMS in real time, whereas SIGINT or electronic intelligence (ELINT) are intended to support future analysis and operations.[4]

Unlike objects physically moving through the air or along the ground or sea, electromagnetic energy travels at the speed of light and often does not stop at walls, boundaries, or exclusion zones. As a result, civilian, military, and environmental emissions cannot be separated like maritime or air traffic. To cope with the resulting congestion, U.S. forces rely on electromagnetic battle management (EMBM) processes and capabilities to coordinate military communications, sensing, and EMSO and deconflict them from civilian and non-combatant users. For example, EA operations must be coordinated with passive sensors to avoid the jammer being classified as a threat as well as with friendly and civilian radios and radars to prevent inadvertent interference. The congestion facing U.S. forces will likely increase as military EMS access is constrained by the need to allocate more spectrum to 5G mobile communications, expanded Wi-Fi coverage, and ubiquitous sensing and communications on vehicles and consumer products.

The EMS is also becoming more contested. Adversaries, most prominently the PRC and the Russian Federation, are countering U.S. military operations in the EMS using passive sensors and jammers to exploit the dependence of expeditionary U.S. forces on active radars for air defense and long-range RF communications for command and control (C2). As the “home team” in most likely military conflicts, U.S. adversaries can rely to a greater degree on wired communications, multistatic and passive sensing, and their understanding of local conditions to gain an advantage in a highly contested electromagnetic environment.[5]

The long-term EMS competition

The adoption of passive or multistatic sensors and less-detectable communications by PRC and Russian armed forces reflects the latest phase of a longstanding competition for EMS superiority that started with the creation of wireless radios and their employment in large-scale military operations during World War I. This early phase of the EMS competition was exemplified by the active use of radios to coordinate troop movements and direct fires and of passive direction-finding (DF) equipment to locate or listen to enemy radio transmissions.

While communications jamming emerged during this first phase of the EM warfare competition, it was not widely employed by military combatants. Operators of rudimentary radios realized that keying their systems could drown out with white noise the transmissions of other radios operating at the same frequencies. This tactic had limited operational value, since it also prevented the jamming force from using the same radio frequencies, and the jamming victim could use alternate means of communicating during the slow-moving operations of the early 20th Century. Moreover, commanders often gained more benefit from exploiting an enemy's radio transmissions for position information or intelligence rather than disrupting them.

The first phase of the EMS competition could be characterized as one of active networks and passive countermeasures in which radios and radars were used to find enemies and coordinate friendly operations, and DF systems were used to locate enemy transmissions or listen to their communications. The shift to the competition's second phase of active networks versus active countermeasures occurred during World War II when technological advances made airborne radars and jammers practical, and the increased tempo of warfare incentivized combatants to jam enemy transmissions as well as intercept and exploit them.

The air defense mission, in particular, helped spur the active network versus active countermeasures competition. Before the advent of air-delivered precision guided munitions during the Cold War, the effectiveness of bombing raids depended in large part on the accuracy of aircraft navigation systems. German air defenders exploited British bombers' use of radio beacons or radar navigation by deploying jammers and decoys to cause bombers to miss their targets. Allied forces responded with updated navigation systems and airborne jammers designed to obscure German air defense radars.[6]

The EMS competition entered is third phase during the late Cold War. As Soviet military sensors, surface-to-air missiles and anti-ship missiles grew in sophistication and number, DoD sought to leverage emerging stealth technologies as a means to break out of the active sensor and countermeasure competition. Since radars were the most capable contemporary systems for detecting aircraft and ships at long ranges, DoD initially emphasized stealth techniques and technologies to reduce the radar cross section of platforms. Stealth was complemented by passive sensors and sensors with waveforms and adjustable power levels to reduce the electromagnetic emissions of stealth platforms that could be detected by an enemy's passive sensors.[7]

DoD's shift toward stealth and low-power EMS capabilities was abruptly curtailed after the end of the Cold War. In the absence of significant competitors, DoD decided to sustain and improve its active networks based on systems such as the SPY-1 shipborne radar or E-3 airborne warning and control system (AWACS) and active countermeasures such as the EF-111 and EA-6B airborne electronic attack aircraft and SLQ-32 shipboard EW system. DoD halted B-2 stealth bomber production at 21 aircraft, and the Air Force was directed to procure only 187 operational F-22 aircraft.[8] Similarly, DoD capped procurement of DDG-1000 stealth destroyers at three ships and replaced its radar with a less capable one.[9]

Unfortunately, the shift to the third phase of EMS operations did not end just because DoD decided to truncate its procurement of stealth and less-detectable EMS capabilities. Adversaries such as the PRC and Russia developed their own low-observable platforms, advanced sensor and communication networks, and countermeasures designed to defeat America's Cold War-era active EMS systems, upgraded versions of which demand the majority of DoD EMS spending today.[10]

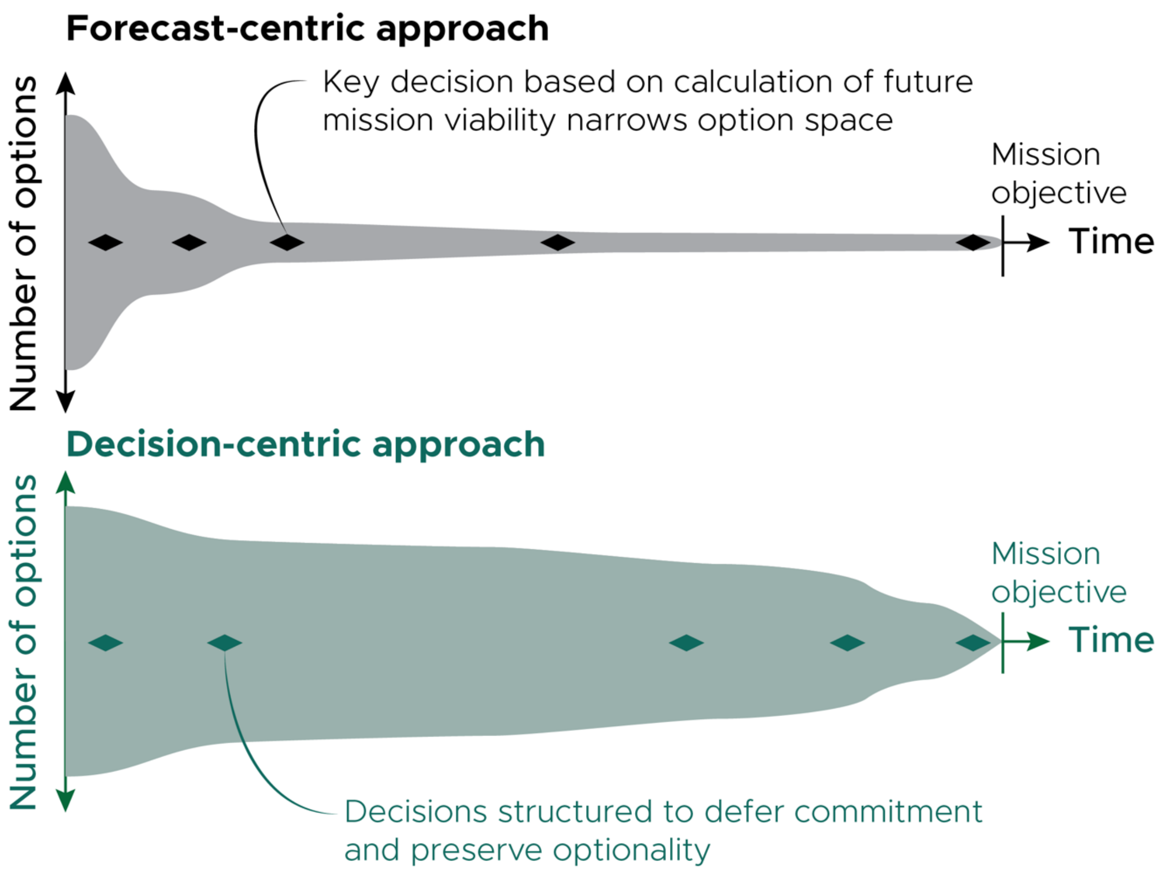
Addressing today's EMS challenges and opportunities

Restoring a U.S. advantage in the EMS will become more difficult as defense budgets come under pressure from costs to combat the ongoing COVID-19 pandemic, respond to economic recession, and service the growing national debt.[11] Given the increasing variety of adversary countermeasures and diverse demands for commercial spectrum, attempting to modify or replace U.S. military EMS systems in response to each new threat or civilian encroachment is likely to be unaffordable and continually late to need.

DoD's forecast-centric planning approach, embodied in the Joint Capabilities Integration and Development System (JCIDS), is ill-suited to identify capabilities that solve DoD's EMS challenges in a fiscally constrained and technologically dynamic environment.[12] Forecast-centric planning bases new requirements on the anticipated gaps between capabilities needed to execute desired concepts in future operations and a military force's current or projected capabilities. This analytic approach depends on assumptions regarding the scenarios in which conflict is likely to occur, the capabilities and tactics to be used by opponents, and the probable actions of U.S. allies and partners. The need to make multiple, interdependent assumptions reduces the accuracy of forecast-centric planning, and when assumptions prove incorrect, budget constraints could reduce the force's ability to adapt.

To regain enduring EMS superiority under today's conditions of technological and fiscal uncertainty, DoD will need to adopt a decision-centric planning approach in which adaptability is a more important metric than predicted performance against a particular threat in a specific scenario. In contrast with forecast-centric planning's mobilization of resources to efficiently develop a single solution, decision-centric planning would seek to preserve options for as long as possible within a mission or over a competition. Within operational timeframes, the optionality afforded by a more adaptable force could allow commanders to make faster and more effective decisions, while the complexity imposed on the enemy would degrade its decision-making process. Over strategic and industrial timescales, increasing the adaptability of military systems enables capability developers to leap ahead of an opponent's advancements and deconflict operations with civilian or commercial activities.

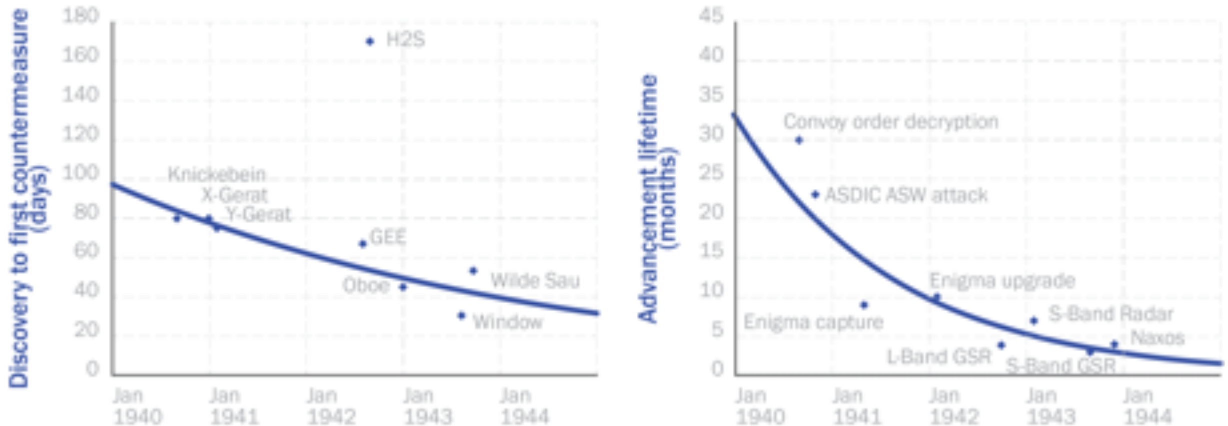
Figure 2: Forecast-centric versus decision-centric capability planning



Source: Bryan Clark, Dan Patt, and Timothy A. Walton, *Implementing Decision-Centric Warfare: Elevating Command and Control to Gain and Sustain an Optionality Advantage in Military Conflict and Competition*, (Washington, DC: Hudson Institute, 2021), p. 11.

Adaptation is a proven path to sustaining EMS superiority in an extended conflict or confrontation. During World War II, for example, the anti-submarine warfare–submarine competition and bombing campaigns over Germany were won by the Allied powers in part because U.S. and British militaries were able to field a more rapidly evolving set of EMS capabilities on their ships and aircraft compared to the Axis powers. The accelerating move-countermove competition that resulted is depicted in Figure 3.[13]

Figure 3: EMS systems innovation during World War II



Source: John Stillion and Bryan Clark, *What It Takes to Win: Succeeding in 21st Century Battle Network Competitions* (Washington, DC: CSBA, 2015), https://csbaonline.org/research/publications/what-it-takes-to-win-succeeding-in-21st-century-battle-network-competitions.

Note: Left graph: Knickebein, X-Great, and Y-Great were German radio navigation aids used to direct bombers to targets in the UK; GEE and Oboe were radio navigation aids for British bombers attacking Germany; Wilde Sau was a German air defense fighter tactic; and Window was a British radar-obscuring chaff. Right graph: ASW = anti-submarine warfare; GSR = German Search Receiver; ASDIC = Allied Submarine Detection Investigation Committee. Enigma was a German code machine.

The U.S. military is unlikely to repeat the Allied success of World War II with today's generation of platforms and EMS systems. Modern U.S. ships and aircraft are monolithic and highly integrated. Incorporating a new sensor, communication system, or countermeasure in today's platforms can take years of software development, hull or airframe modification, electromagnetic deconfliction, and procedural evolution beyond the task of creating the new EMS system itself. Unfortunately, most of DoD's EW procurement and research and development (R&D) investment is tied up in these integrated, platform-based systems.

DoD will need to adopt new EMS technologies that allow it to gain a lead in the move-countermove cycle with military competitors and the growing spectrum needs of civilian users. To improve their ability to evolve between operations, EMS systems will need to be increasingly software-based and modular, allowing components or systems to be more easily upgraded or modified to incorporate new techniques and technologies.

DoD's recently released EMS Superiority Strategy supports the importance of adaptability in its central idea that U.S. forces need to maneuver in the EMS to avoid threats, exploit opportunities, and share spectrum with civilian users. The strategy is notable for its emphasis on creating a force that uses agility, battle management, open architecture, and virtual and constructive training systems to achieve freedom of action in the EMS. Each of the strategy's goals pursues this overall approach, as summarized below.

- **Goal 1: Develop superior EMS capabilities.** DoD should create open architecture multifunctional EMS systems that can sense, communicate, and maneuver in the spectrum as directed by EMBM capabilities while avoiding threats and counter-detection through their signal characteristics and maneuver. This method for gaining superiority is different from the attempt to dominate opponents in individual system-versus-system competitions, which was often the model of DoD's post–Cold War EMS capability development.

- **Goal 2: Evolve to an agile, fully integrated EMS infrastructure.** DoD should prioritize better integration and interoperability between intelligence and operational EMS activities to improve responsiveness; the department should also increase reliance on virtual and constructive training to raise proficiency in agile, networked EMS operations without risking adversary intelligence gathering during open-air exercises.

- **Goal 3: Pursue total force EMS readiness.** DoD should professionalize personnel in EMS-dependent fields to enable the career-long development needed for more sophisticated and dynamic EMS operations. To improve unity of effort between EMS specialists and other operators and technicians, the department should incorporate EMS doctrine into force-wide training.

- **Goal 4: Secure enduring partnerships for EMS advantage.** DoD should emphasize interoperability with allies and partners to help ensure that technical advances in DoD EMS operations will not be undermined by other friendly activities. To accelerate the technology improvement cycle, the Pentagon should also enhance its collaboration with industry and professional organizations.

- **Goal 5: Establish effective EMS governance.** DoD should adopt a sustainable governance structure for EMS capability development efforts to ensure the diverse array of EMS-dependent programs and activities is being coherently pursued in support of the strategy.[14]

The EMS Superiority Strategy's goals emphasize the importance of adaptable technologies, but adaptability alone will not yield an advantage if the underlying technologies do not mitigate challenges and exploit opportunities. For example, high-power broadcast radios or scanning search radars can be made highly adaptable using artificial intelligence (AI)-enabled controls, but their risk of counter-detection makes them a poor choice for operations against revisionist powers like the PRC that can deploy numerous distributed passive radiofrequency (RF) sensors in areas where they intend to initiate conflict.

Instead of merely pursuing adaptability, DoD should establish technology priorities that would help U.S. forces gain an advantage against their primary adversaries and which would essentially form the centerline of the decision-centric planning space shown in Figure 1. In the Hudson Institute's recent study, we used the technique of net assessment to identify EMS technologies that leverage fundamental asymmetries between the DoD and its great power competitors to address the U.S. military's EMS challenges and opportunities.[15]

Asymmetries

DoD will need to focus its efforts on concepts and capabilities that provide U.S. forces enduring advantages against the PLA and Russian Armed Forces while mitigating U.S. disadvantages. The net assessment methodology identifies these opportunities based on asymmetries between competitors the U.S. and opposing militaries, such as those described below.[16]

Geography: The PRC and Russian militaries will likely be the home team in future military confrontations, given their ongoing gray-zone operations and stated interests in neighboring countries such as Taiwan for the PRC and the Baltic countries for Russia. As a result, the PLA and Russian Armed Forces can rely to a greater degree than the expeditionary U.S. military on wired communications and can employ passive and multistatic sensors that require multiple networked arrays and a sophisticated understanding of the local electromagnetic operating environment.[17]

Command, Control and Communications: The PLA can rely on redundant and resilient communications networks to support a relatively fixed C2 structure of unit commanders, theater commanders, and the Central Military Commission. Russian Armed Forces are more likely to build initial plans and rely on local commanders to execute them, or to improvise when conditions change, or communications are degraded.

The U.S. military exhibits elements of both the PRC and Russian approaches. DoD aspires to create the PRC's level of communications reliability so distant commanders at regional headquarters can manage operations across a theater. Under the concept of mission command, U.S. military doctrine directs local commanders to use their initiative and improvise when communications break down.

Technological innovation: The PLA's concept of system destruction warfare requires development of countermeasures that address specific nodes of U.S. systems of systems. The PLA can leverage the PRC's robust commercial electronics industrial base to develop new capabilities, enabling it to field a comprehensive and changing collection of EMS systems. Russia lacks the PRC's military budgets and fusion with civilian industry, leading the Russian Armed Forces to incrementally adapt existing EMS systems.

DoD largely pursues two tracks in new EMS technologies: new capabilities that are designed to support innovative operational concepts, and improvements to existing systems that counter new adversary capabilities. Because new concepts are not associated with existing major programs, the DoD approach results in the majority of U.S. EMS investment going toward incremental advancements of legacy systems that chase adversary initiatives rather than toward new innovations that create dilemmas for opponents.

Employment of AI: The PRC, Russian, and U.S. militaries are all aggressively pursuing AI as an element of their overall force development, but with different priorities for operational systems compared to management and support capabilities. Whereas DoD has prioritized AI incorporation into operational systems for tactical intelligence, platform control, and maintenance, the PLA and Russian Armed Forces have focused AI implementation on C2, management support systems, and intelligence, surveillance, and reconnaissance (ISR).

EMS capability governance: Significant asymmetries exist between the DoD and its competitors regarding the organizations that govern EMS capabilities. The PLA developed a unified governance structure for EMS policy and capability requirements, which parallels the Russian Armed Forces' EW Commander and staff. The U.S. military, in contrast, divides responsibilities for doctrine and strategy between U.S. Strategic Command, the EW Executive Committee (EXCOM), and the EMSO Cross-Functional Team (CFT). Moreover, DoD does not give any of these bodies the authority to direct EMS-related spending or acquisition, reducing their ability to implement policy.

Deployment of EW capabilities: Although the PLA, Russian Armed Forces, and DoD all field operational- and tactical-level EW capabilities through their service branches, the scale and depth of deployment varies significantly. Because of the value they place on EW as an element of their respective military strategies and operational concepts, the PRC and Russian militaries equip units with offensive and defensive EW systems and personnel down to the ground force company, aviation squadron, and naval or paramilitary ship level. U.S. EW capabilities are deployed to varying echelons depending on the service, but generally are held at higher levels of command than in the PLA or Russian Armed Forces. Additionally, PLA and Russian Armed Forces units have employed broad area EW systems against adversaries and enemies with greater frequency than U.S. forces, suggesting EW authorities may be delegated to lower levels of command.

EMSO: The U.S. military introduced the EMSO concept to create a coherent framework for EW operations to control the EMS and EMBM to coordinate EMS activities such as EW, sensing, and communications. The PRC and Russian militaries do not have publicly released concepts for unified EMS operations, and largely treat EMS control through EW separately from communications, sensing, and spectrum management activities.

Technology Priorities

The asymmetries revealed by net assessment help identify significant U.S. advantages or vulnerabilities in EMS operations, including shortfalls that could be turned into advantages or are foundational and therefore unlikely to be overcome. EMS technology priorities should address U.S. strengths and weaknesses by supporting capabilities in four main categories: capabilities enabling DoD to obviate, rather than overcome, fundamental challenges; capabilities that undermine adversary advantages; capabilities that turn challenges into opportunities; and capabilities that exploit existing U.S. strengths.

The net assessment methodology accepts risk because it does not attempt to solve every potential future capability gap, which is an acceptable trade-off given DoD's time and fiscal constraints. The Hudson Institute study recommends that DoD prioritize the following areas to gain EMS superiority and address the growing diversity of civilian users. Some important technologies, such as attritable EW platforms, are mentioned but not specifically called for because they are already being pursued by DoD and therefore are not a new technology priority.

Capabilities to obviate, rather than overcome, fundamental challenges: The PLA's concept of system destruction warfare uses the PRC's fusion of military and civil sectors to create a comprehensive set of

EMS countermeasures designed to target key U.S. battle network nodes and platforms. Continuing to engage in an extended move-countermove competition with the PLA is costly and time-consuming. Therefore, U.S. EMS capability development should focus on adaptive capabilities that can reduce the predictability of U.S. battle network operations.

Capabilities that undermine adversary advantages: The PRC and Russian home team advantage could be countered in part by new technologies that improve the EP capabilities of U.S. forces and reduce their risk of counterdetection; specifically:

- **Passive and multistatic electromagnetic (EM) sensing:** U.S. forces, as the away team, will need to reduce their EM emissions and signatures across the RF, IR, and visual spectra to avoid counter-detection and targeting by PRC or Russian forces.
- **Passive and multistatic air and missile defense:** To reduce the vulnerability of air and missile defense systems, DoD will need to field passive and multistatic sensors that can detect and track subsonic, supersonic, and hypersonic aircraft and weapons.
- **Networked ES:** Passive receiving arrays need to securely communicate with one another or with multistatic emitters to enable more precise sensing.
- **Networked EA:** Systems that conduct high-risk EA operations inside contested areas will need to be expendable or inexpensive enough to be attritable. Small and cheap unmanned EA platforms can rely on proximity and coherently combined transmissions to make up for their lower power—an approach that places a premium on secure networking.
- **Low Probability of Intercept/Low Probability of Detection (LPI/LPD) active monostatic sensing:** As an expeditionary force, the U.S. military may have difficulty sustaining multiple passive sensor systems in position to support operations like air and missile defense, and therefore will need active radars to achieve the necessary precision for engagements. Radars, however, will need features that reduce their likelihood of revealing the defensive system's exact location.
- **Multifunction ES and EA capabilities:** The cost and complexity of using larger numbers of distributed ES and EA vehicles could be reduced in part by ensuring that DoD EW systems are able to perform either sensing or EA operations.

Capabilities that turn challenges into opportunities: As noted above, the PRC and Russian military's focus on potential vulnerabilities of U.S. battle networks could be turned into a disadvantage if U.S. force packages, configurations, and operational concepts are less predictable using technologies such as:

- **Cognitive wideband EMS systems:** The U.S. military could dramatically accelerate its EMS capability move-countermove cycle by fielding sensor, communication, and EW systems that can operate over multiple gigahertz of frequency spectrum and react to adversary operations in real time by developing and employing new courses of action using AI-enabled algorithms.
- **Automated EW system reprogramming:** Accelerating automated and AI-enabled reprogramming would improve the adaptability of systems that are not yet able to react in real time.
- **Decision support aids and communications management systems:** DoD could turn the challenge of contested communications environments into an advantage by giving junior commanders decision support systems that help them develop courses of action in the absence of connectivity with senior leaders and staffs.

Capabilities that exploit existing U.S. strengths: The U.S. military has adopted new approaches to EW and EMSO, supported by new training and capability integration approaches, that could substantially increase the adaptability and complexity of U.S. operations. These efforts should be accelerated by prioritizing relevant technologies:

- **Virtual and constructive EW/EMSO environments:** The U.S. military could exploit its investments in live, virtual, and constructive (LVC)-based EMSO experimentation and training by accelerating the introduction of virtual and constructive tools and environments at each organizational level, especially at home stations to support ongoing training and experimentation.
- **Electromagnetic battle management (EMBM) systems, including AI:** The U.S. military could capitalize on the PLA's and Russian Armed Forces' lack of EMSO doctrine and exploit the emerging generation of more adaptable EMS capabilities by accelerating the fielding of operationally useful EMBM systems.
- **Open architecture hardware standards:** Combined with a move away from monolithic, multi-mission EMS platforms, increased adoption of open architectures in U.S. military platforms and vehicles would allow use of more modular EMS systems that could be more easily exchanged and modified.
- **Open architecture software tools:** Another approach to open architecture is promoting interoperability between systems. DoD should accelerate the fielding of toolkits like the System-of-systems Technology Integration Tool Chain for Heterogeneous Electronic Systems (STITCHES) that build software interfaces on demand to allow disparate networks to communicate.

Conclusion

DoD is at a crossroads in development of EMS-related technologies. The 2020 EMS Superiority Strategy and EMSO concept advance new approaches to regain an advantage and accommodate growing civilian uses by improving the adaptability of U.S. EMS capabilities. The resulting expansion of options could allow DoD to accelerate or break out of today's move-countermove EMS technology innovation cycle.

Making the shift to more dynamic, agile, and flexible EMS operations, however, will require accepting risk in traditional methods of controlling the spectrum. The U.S. military lacks the time and resources to gain EMS superiority against PRC and Russian forces using a symmetric system versus system approach. By the time DoD catches up, the PLA or Russian Armed Forces could exploit their EMS advantage to support aggression against their neighbors. DoD's choice is whether to accept continued erosion of its edge in the EMS or to make bold bets on the technologies most likely to circumvent or reverse the inherent advantages enjoyed by its great power competitors.

The technology priorities described above represent the U.S. military's best opportunity to establish enduring EMS superiority. They are all being pursued by DoD to varying degrees, but most are merely being sustained rather than accelerated in support of a new approach to EMSO. To reverse trends of the last three decades and give the PRC and Russia challenges to address, funding and attention will need to shift to these new priorities and away from legacy programs that helped win the Cold War.

[1] The most significant recent authoritative EW studies include the following: Defense Science Board (DSB), *21st Century Military Operations in a Complex Electromagnetic Environment* (Washington, DC: Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics, 2015), https://apps.dtic.mil/dtic/tr/fulltext/u2/1001629.pdf; Government Accountability Office, *Electromagnetic Spectrum Operations DoD Needs to Address Governance and Oversight Issues to Help Ensure Superiority* (Washington, DC: U.S. Library of Congress, 2020), https://www.gao.gov/assets/gao-21-64.pdf; Madison Creery, "The Russian Edge in Electronic Warfare," Georgetown Security Studies Review, June 26, 2019, https://georgetownsecuritystudiesreview.org/2019/06/26/the-russian-edge-in-electronicwarfare/.

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[12] U.S. Joint Staff, "Charter of the Joint Requirements Oversight Council (JROC) and Implementation of the Joint Capabilities Integration and Development System (JCIDS)."

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[15] The discussion of asymmetries and technology priorities that follow are drawn from Bryan Clark, Timothy A. Walton, Melinda Tourangeau and Steve Tourangeau, "The Invisible Battlefield: A Technology Strategy for EMS Superiority," (Washington, DC: Hudson Institute, 2021), https://www.hudson.org/research/16738-the-invisible-battlefield-a-technology-strategy-for-us-electromagnetic-spectrum-superiority.

[16] Net assessment is not explained in detail here, but more detail can be found in James G. Roche and Thomas G. Mahnken, "What is Net Assessment?" in Thomas G. Mahnken, ed., *Net Assessment and Military Strategy: Retrospective and Prospective Essays* (Amherst, NY: Cambria Press, forthcoming in 2020); Eliot Cohen, "Net Assessment: An American Approach," JCSS Memorandum no. 29, April, 1990, available at https://www.inss.org.il/publication/net-assessment-an-american-approach/; George E. Pickett, James G. Roche, and Barry D. Watts, "Net Assessment: A Historical Review," and Stephen Peter Rosen, "Net Assessment as an Analytical Concept," in A.W. Marshall, J.J. Martin, and Henry S. Rowan, eds., *On Not Confusing Ourselves* (Boulder, CO: Westview Press, 1991); and Paul Bracken, "Net Assessment: A Practical Guide," Parameters, Spring 2006.

[17] US Department of Defense, "Military and Security Developments Involving the People's Republic of China 2020: Annual Report to Congress," 2020, p. 74, https://media.defense.gov/2020/Sep/01/2002488689/-1/-1/1/2020-dod-china-

military-power-report-final.pdf; Glen E. Howard and Matthew Czekaj, eds., *Russia's Military Strategy and Doctrine* (Washington, DC: Jamestown Foundation, 2019), pp. 164–76, https://jamestown.org/wp-content/uploads/2019/02/Russias-Military-Strategy-and-Doctrine-web-1.pdf?x30147.