REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
30-04-2020	Master of Military Studies (MMS) thesis	AY 2019-2020

4. TITLE AND SUBTITLE
Electromagnetic Spectrum Operations: An Assessment of the U.S. Marine Corps Ability to Compete in the Electromagnetic Spectrum

5a. CONTRACT NUMBER
N/A

5b. GRANT NUMBER
N/A

5c. PROGRAM ELEMENT NUMBER
N/A

6. AUTHOR(S)
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5d. PROJECT NUMBER
N/A

5e. TASK NUMBER
N/A

5f. WORK UNIT NUMBER
N/A

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
USMC Command and Staff College
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2076 South Street
Quantico, VA 22134-5068

8. PERFORMING ORGANIZATION REPORT NUMBER
N/A

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
N/A

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)
N/A

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

As the Marine Corps focuses on great power competition, it must address shortfalls in training and equipment to maintain resilient communications in a contested electromagnetic spectrum (EMS). Incorporating war gaming and data visualization software can mitigate shortfalls in equipment and training. Incorporating existing equipment systems such as Free Space Optics and Global Broadcast System will improve communications resiliency in the EMS.

15. SUBJECT TERMS
Electromagnetic Spectrum (EMS); Electromagnetic Spectrum Operations (EMSO); contested environment; Electronic Warfare (EW); U.S. Marine Corps; Great Power Competition

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			USMC Command and Staff College
Unclass	Unclass	Unclass	UU		19b. TELEPHONE NUMBER *(Include area code)* (703) 784-3330 (Admin Office)

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MASTER OF MILITARY STUDIES

TITLE:
Electromagnetic Spectrum Operations: An Assessment of the US Marine Corps Ability to Compete in the Electromagnetic Spectrum.

SUBMITTED IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF
MASTER OF MILITARY STUDIES

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AY 2019-20

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Date: 20200430

Executive Summary:

Title: Electromagnetic Spectrum Operations: An assessment of the US Marine Corps ability to compete in the electromagnetic spectrum.

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Thesis: As the US Marine Corps transitions its focus to Great Power adversaries, it must address shortcomings in training and equipment to maintain resilient communications in the Electromagnetic Spectrum (EMS) or risk being unable to communicate in future conflict.

Discussion: US Marine Corps operations rely on the electromagnetic spectrum to support critical functions, to include, command, control, communications, intelligence, surveillance, and reconnaissance. During recent large-scale combat operations, the US Marine Corps faced a relatively low-tech enemy in terms of technological abilities to jam or contest the EMS. With the rise of great power competition, this threat has changed. Peer adversaries are prepared to challenge the US military's ability to operate in a contested electromagnetic environment. As the US Marine Corps focuses on peer adversaries, the service needs to improve its understanding of, and proficiency in operating in this contested environment. The US Marine Corps should examine advances in wargaming technology and invest in communications systems more resilient to electromagnetic interference in order to train and equip the force for peer competition. Advancements in wargaming technology provide the service a valuable learning tool to prepare future leaders to operate in this ill-defined and unfamiliar environment. Equipment investments will achieve a diverse and resilient communications system capable of surviving conflict with peer nation states.

Conclusion: The US Marine Corps currently lacks the training, or equipment to conduct military operations in a contested electromagnetic spectrum environment. Re-visiting old doctrine as well as introducing electromagnetic spectrum operations into wargaming and service level exercises will increase the ability of the US Marine Corps to compete with peer adversaries.

DISCLAIMER

THE OPINIONS AND CONCLUSIONS EXPRESSED HEREIN ARE THOSE OF THE INDIVIDUAL STUDENT AUTHOR AND NO NOT NECESSARILY REPRESENT THE VIEWS OF THE MARINE CORPS COMMAND AND STAFF COLLEGE OR ANY OTHER GIVERNMENT AGENCY. REFERENCES IN THIS STUDY SHOULD INCLUDE THE FOREGOING STATEMENT.

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Preface

As a US Marine Corps Communication Officer, the electromagnetic spectrum is a critical element to the success or failure of my mission to provide communications systems and connectivity. Much like the early days of cyber warfare, the Marine Corps is slowly developing an understanding of the EMS as a medium to maneuver in and an environment that is not guaranteed for friendly use. Participation in the Krulak Center war game Sea Dragon as well as in the Gray Scholars Partnership with the Marine Corps Warfighting Lab significantly contributed to my understanding of the challenges the Marine Corps faces in the future operating environment. Thank you to the faculty and staff of the Marine Corps Warfighting Lab and Command and Staff College for supporting the Gray Scholars Program and feeding the desire of career-level officers to pursue their passion. Special thanks to Dr. Brandon Valeriano for his support and guidance throughout this endeavor.

Introduction

The 2018 National Defense Strategy acknowledges the rise of revisionist powers, highlighting Russia and China as "long-term, strategic competitors" and disruptors of the global security environment.[1] As the US Marine Corps transitions to competition with these nations, it must address shortcomings with training and equipment in order to compete in the electromagnetic spectrum or risk being unprepared for the next conflict. Because the electromagnetic spectrum (EMS) provides the physical medium through which the modern Marine Air Ground Task Force (MAGTF) depends for many command and control, communications, intelligence and combined arms applications. Protecting the use of the EMS is a requirement for achieving mission success. In this paper, I will discuss the relevance of the electromagnetic spectrum to modern military warfare, and reliance of current military communications systems on the EMS. Second, I will highlight Russian and Chinese military capabilities to contest the EMS and provide an examination of US Marine Corps strategy in light of these adaptations. Finally, I will evaluate the implementation of Marine Corps strategy and offer recommendations for the service to integrate wargame-based training and equipment solutions to improve communication resiliency in EMS.

Joint doctrine defines the electromagnetic spectrum as "the entire range of frequencies of electromagnetic radiation," extending from gamma rays to the longest radio waves and including visible light.[2] Nearly every modern weapons system -airplanes, satellites, tanks, ships, and radios- depend on the spectrum to operate.[3] The nature of military communications is entirely reliant on the EMS to support tactical to strategic level military organizations and decision makers. The marine corps communication system is no different. The Marine Corps leverages the full breath of the military assigned RF spectrum to enable communications and support command and control throughout the service. From the tactical radio, to billion-dollar satellites, the Marine Corps relies on the EMS for all levels of operations. This singular and complete reliance on the EMS is a potential vulnerability for military operations in a contested environment.

As the US military transitions to focus on peer adversaries, it is important to understand adversary perspectives on the use of the EMS to support their operations as well as their capabilities to deny friendly use of the EMS. Much has been written about Russian New Generation Warfare, and the Chinese philosophy of System Destruction Warfare. These philosophies and capabilities which support them are critical for military professionals to understand, particularly as they relate to challenging the US military's access to the EMS. Near peer adversaries such as Russia and China study how the US military conducts operations in order to inform their own equipment procurement and psychological approach to countering US systems and methodologies. Specifically, these nation-states have focused on contesting US's the ability to access and leverage the EMS for military operations.

The US Marine Corps has published strategy and operating concepts prioritizing operations in the EMS, however, the service has failed to support this guidance with effective training and equipment to ensure Marines are prepared for conflict with peer nations.[4] Introducing wargaming software, such as DAPRA's PROTEUS program into existing training scenarios can enhance the understanding of Electromagnetic Spectrum Operations (EMSO) and better prepare the service for peer conflict. Additionally, by incorporating existing equipment into training exercises in greater quantities, the service can diversify its use of the spectrum, thereby improving communication resiliency.

Defining the EMS

Communication technologies are proliferating globally, and reliance on these technologies for communications and daily transactions is increasing. For the purpose of this work, my research focuses on US military operational reliance on radio frequency communications, from 3MHz to 300GHz. This range encompasses the commonly known High Frequency (HF), Very High Frequency (VHF), Ultra-High Frequency (UHF), Super-High Frequency (SHF), and Extremely High Frequency (EHF) bands. These bands provide the backbone of military communications and are critical for mission success.

The distinction between cyber and EMSO operations can be nuanced, and the topics often overlap and interrelate. In this paper, analysis on the interference in the EMS is strictly from a radio frequency (RF) perspective. RF systems provide the connection or transmission path over which cyber network information passes. There are far more interdependencies and overlaps with topics such as cyber network operations and Electronic Warfare (EW), while valuable to the overall conversation on EMS interdependencies, these relationships are outside the scope of this paper.

A key concept relevant to the discussion of protecting the EMS is the use of electronic warfare. EW includes "any military action involving the use of electromagnetic and directed energy to control the electromagnetic spectrum or attack the enemy."[5] This type of warfare allows military commanders to protect valuable electronic systems while denying adversaries access to their own electronic systems. EW is also used in a support capacity to enable military functions such as intelligence, surveillance, and reconnaissance. EW capabilities are critical components to enable EMSO and protect the EMS for friendly use.

Although the technology and techniques for using the EMS evolve and change over time, the importance protecting and defending the EMS in military operations remains a timeless aspect of modern warfare. Advances in technology enable information sharing at rates and speeds never experienced previously. Beginning with the telegram, and continuing to evolve today, the reliance on the EMS to transmit this information continues to grow. The US military use of the EMS provides a healthy topic for analysis, specifically as it relates to reliance on the EMS for military communications.

State of USMC Electromagnetic Spectrum Operations Past to Present.

Background: EMS in US Marine Corps operations.

The US military's use of the electromagnetic spectrum dates back to the 1860s when the US Army used the telegraph to transmit information over long distances[6]. As radio frequency use became more prevalent in the early 1900s, the US military adapted this new technology to support farther reaching and more complex campaigns.[7] Radio communications developed in the early 1900s became commonplace in during WWI, allowing information to be transmitted over long distances in a short amount of time. This new capability increased the tempo of operations and institutionalized the use of the EMS to support military operations. Radio frequency communications became the preferred means to communicate in military operations. HF, VHF, and later UHF communications were relied on to facilitate combined arms, medical evacuation, resupply, and intelligence dissemination from tactical to strategic levels. With improvements in technology, as well as the increased appetite for information, reliance on the EMS to send and receive information continued to increase.

During the 20th century, improvements in Radio technology, satellite communication and the advent of digital communication increased military use and reliance on the EMS. During the 1970s and early 1980s, the US Marine Corps led the DoD in institutionalizing Electronic Warfare (EW). In 1979, the service published Operational Handbook 3-4, Electronic Warfare Operations Handbook, describing in detail, the operational concepts required to survive and win an engagement with Russia. As the Cold War era closed, the military continued to incorporate new EMS related technologies such as GPS navigation and precision weaponry. Satellite communications allowed the transmission of data files and near-real-time global communications from tactical commanders to the highest levels of the military. With relative technological overmatch against adversaries, EMS doctrine evolved to focus on offensive EW as a means of denying adversary communications, intelligence collection and situational awareness.

Use of the EMS evolved during conflict in Iraq and Afghanistan with the use of radio controlled improvised explosive devices (RC-IEDs) to target US military forces. Bomb makers used mobile telephones and garage door openers to provide standoff between the bomb and its human initiator. The lethality and pervasiveness of these devices required a solution and US military response. The US military fielded equipment and provided new doctrine to deal with this new threat. Vehicle modifications to incorporate active radio frequency jamming systems became commonplace throughout both Iraq and Afghanistan. Doctrine and military research focused on defeating RC-IEDs by various mechanisms, such

as active RF jamming to deny the ability to initiate the explosive device via electronic means. This adaptation cycle highlights the importance of controlling the EMS for friendly use, while denying it to adversaries.

With the emergence of peer and near-peer capabilities capable of denying access to the EMS, a renewed emphasis is being placed on reviving EMS doctrine and protection capabilities. Numerous articles have been published in the Marine Corps Gazette articulating the vulnerabilities of current communications systems to adversary interference in the EMS. National level military leaders are also engaged in this discussion through numerous briefings about the military capabilities of potential adversary nations. In recent years, realizing the importance of information to influence both internal and foreign audiences, the US military embraced the concept of information warfare. In 2019, the US Department of Defense established Information Operations as the 7th warfighting function, acknowledging the importance of information as a key aspect of military operations. The Marine Corps published multiple concepts and strategies focusing on operations in the information environment, assured communications, and Electromagnetic Spectrum Operations (EMSO).

In the 21st century, the US military continues to incorporate EMS reliant systems and technologies, increasing and enabling situational awareness and communications. Figure #1 illustrates the variety of military systems which rely on the EMS for functionality. These systems, and systems of systems, have become dependent upon the EMS to function across the range of military operations. A cursory look at the warfighting functions reveals that all functions of joint warfighting, capabilities that are critical for military campaigns, are reliant on the EMS for integration in military operations.

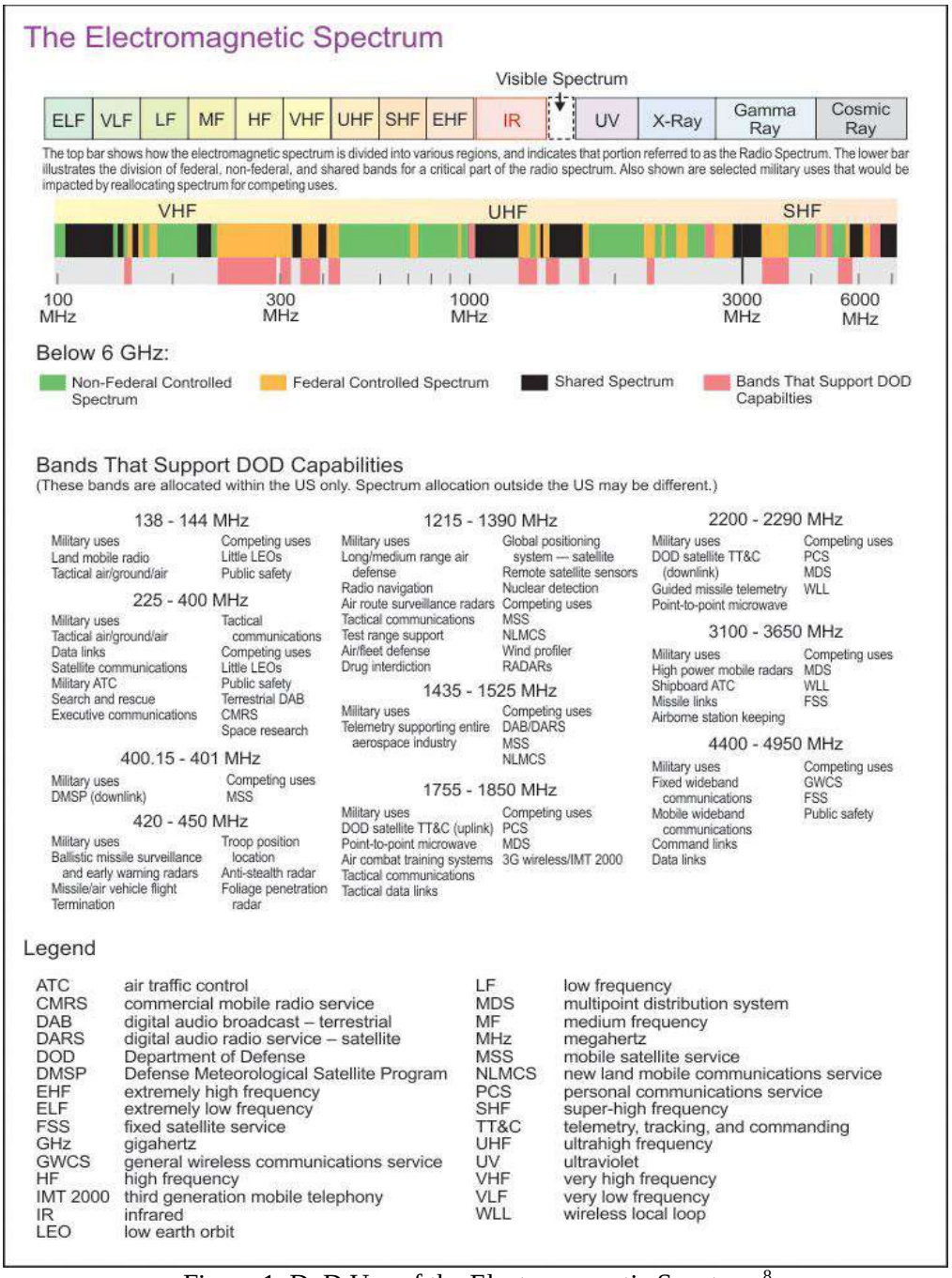

Figure 1. DoD Use of the Electromagnetic Spectrum[8]

Evolution of spectrum reliance

Decades of operating in uncontested electronic environments, proliferated the notion throughout the defense community that the Department of Defense could operate with impunity in the electromagnetic environment. The Global War on Terrorism (GWOT) and subsequent Operations Enduring Freedom and Operation Iraqi Freedom, allowed U.S. military forces to develop static, steady state 24/7 operations centers of increasing size and capability. Due to the enemy's inability to the US military offensively or defensively in the EMS, commander's placed higher priorities on 24/7 access to high data rate communications above communications infrastructure agility and EMS awareness. The

increased priority for instant information and constant connectivity resulted in the normalization of large, immobile, continuously connected, command and control centers. More recent operations in the Middle East and the Baltics have highlighted the contested nature of the EMS in military operations. General Raymond Thomas, the commander of U.S. Special Operations Command is quoted as saying "Right now in Syria, we're in the most aggressive EW environment on the planet from our adversaries… . They're testing us every day, taking our communications down, disabling our AC-130s, etc."[9] In November of 2018, numerous news outlets reported Russian interference during the NATO exercise Trident Juncture which took place in and around Norway. A NATO spokesman told news outlets "Norway has determined that Russia was responsible for jamming GPS signals in the Kola Peninsula during the exercise." A Norwegian defense official went on to say that electronic jamming appears to have become a regular part of the training activities of the Russian land forces over the past year.[10] These vignettes highlight the evolution in understanding of vulnerabilities reliance of military systems

Effectiveness to date

After 9/11 and throughout the GWOT, the U.S. military continued to fight with precision weapons that used unmanned vehicles to provide continuous full-motion video feeds into large combat operations centers. These systems rely on commercial and military SATCOM, GPS. Throughout the past 15 years of conflict, the U.S. military has not experienced a contested electromagnetic environment during major combat operations. Only recently, during operations in Syria and the Baltics, has the US military experienced an environment where adversaries contest the use of the electronic spectrum. As the Marine Corps focuses on peer competition, the threats to the US Military use of the electronic spectrum are significant. The US military has developed a reliance on the EMS during its experience with the GWOT. To be successful in future conflict, the U.S. military and the Marine Corps, in particular, must understand and operate within a contested electronic spectrum environment.

A number of current Marine Corps program of record systems rely heavily, if not entirely on EMS to display and process information. For example, the Marine Corps Command, Control, Computers, Communications, Intelligence, Surveillance, Reconnaissance (C4ISR) enterprise is a system of systems reliant on the EMS to disseminate information to key nodes throughout the C2 or ISR enterprise. The Marine Corps relies on systems such as Theater Battle Management Core System (TBMCS), Global Command and Control System – Tactical Combat Operations (GCCS- TCO), and Joint Battle Command-Platform (JBC-P), formerly known as Blue Force Tracker, to provide fires, and command and control capabilities throughout the MAGTF. These systems require varying degrees of connectivity to other nodes in the system to send, receive, relay, and process information. TBMCS for example, incorporates near real time tracking information from aircraft and missiles to provide commanders with situational awareness of the battlespace. This near-real-time, situational awareness requires information to be transmitted and received through the EMS on a continuous basis, therefore exposing command centers using this system to attack or vulnerability through the EMS. Newly fielded communications systems such as Network On The Move (NOTM), in both air and ground variations, broadcast a high power wireless internet signal between vehicles or aircraft to maintain wireless connectivity. Additionally, systems such as JBC-P receive and transmit GPS positional information from vehicles, aircraft, and ships at regular time intervals in order to provide commanders with accurate and up to date information of all the units in the battlespace. This list contains only a few of the common systems used by the Marine Corps to maintain situational awareness of military operations. Although this list is not all encompassing, it demonstrates the degree to which reliance on the EMS is integrated into critical operational systems and the degree to which the Marine Corps is reliant on the EMS to process and disseminate information.

The use of, and access to the electronic spectrum will be a key factor in future conflict. The Future Operating Environment 2015-2025, published by the Marine Corps Intelligence Activity suggests that maneuver in the EME will be vital for the MAGTF to effectively accomplish its missions.[11] Relative to the EME, the report highlights technology proliferation, information as a weapon, and the battle of signatures as key aspects of the future environment. Each of those aspects requires access to and use of the EME to enable friendly operations or deny the adversary's operations. Based on the MCIA report,

competition in the EMS will be the first critical test of adversary capabilities in the event of conflict between great power nations.

The Emerging Landscape of EMS Competition.

New adversary – great powers

As the US military seeks to reduce its presence in the Middle East after almost 20 years of combat operations, the US military is refocusing on potential future conflicts. Backed by the 2019 National Defense Strategy, the US military is reprioritizing investments and focus on peer and near-peer military competitors. The past two decades of conflict have provided great power nations such as Russia and China a unimpeded opportunity to observe and study how the US military projects military power globally. These nations study the US reliance on satellite communications and GPS, to support drone operations, ISR, and tactical communications and ISR activities. Russian and China have internalized this information and developed methods and technologies to deny the US the advantage of using EMS reliant weapons and information systems in conflict. Realizing the cost of conventional conflict, these countries look to gain asymmetric advantages in the EMS to gain temporal and positional advantages in conflict.

Russia

Russian military actions in the Georgia and the Ukraine provide a valuable example of how the EMS can be leveraged to gain advantages in military conflict. A 2019 Congressional Research Service report[12] on Electronic Warfare highlights advances in Russian ground EW capabilities. Russian ground-based EW has steadily been modernized since the Georgian "five day war" in 2008. Russian modernization has included transforming capabilities as well as restructuring organizations to better integrate EW capabilities. One of the most noteworthy transformations is the inclusion of a dedicated EW Company in main combat arms formations such motorized infantry brigades. The motorized brigade has at least one EW company of more than 100 personnel capable of intercepting and jamming radio, GPS, cellular and radio-controlled explosives such as mines, bombs, and fuses. Integration of EW capabilities within traditional infantry and maneuver units indicates the layered approach the Russians take to incorporating EW at all echelons or military organizations. Additionally, the Russian military invests heavily in strategic EW systems such as the Murmansk-BN. The system has a reported range of 5,000km and can intercept and jam a broad range of enemy communications, to include the entire range of US military communications systems. A high-level Russian General referred to the system as a "National Strategic EW System" as well as an "asymmetric response to the network centric system of combat operations."[13] Significant investments of this type reflect a high level of value placed on these operations by senior leaders within the Russian military. Additionally, Russia does not separate the functions of EW and signals intelligence, providing for a more streamlined method of geolocation and targeting.

In addition to equipment modernization, a 2017 report from the Estonian International Centre for Defense and Security highlights the Russian revolution in military affairs which places emphasis on enabling network-centric approaches to war, including electronic warfare, from a theory and doctrinal perspective. The report is valuable due to its emphasis and analysis of how Russian military professionals think of and approach EW and more broadly, their approach to controlling the EMS. The report analysis Russian military conflict in Chechnya, Georgia, Crimea, Syria, and the Donbas. The central theme which emerges from this analysis is the view that the Russian theory of engagement seeks to first dominate and control the EME by employing systems at the tactical, through strategic levels. Controlling the EME enables the defeat of adversary forces and the success of friendly forces by disrupting enemy information process and supporting friendly IO to persuade public opinion as well as enable military operations. Use of the EME for EW as well as IO prior to, during and after kinetic engagements demonstrates the value the Russians place on controlling the spectrum. Additionally, the Russian perspective that the NATO alliance is potentially weak in offensive EW capabilities and unprepared to control the EME to support NATO use of the EMS.[14] The Russians also demonstrate the ability to learn and refine their EW and IO processes, while using current conflict zones such as Syria to test EW capabilities against NATO systems. The active use and refinement of EW tactics and techniques against NATO forces is perhaps the most

beneficial to the continuous improvement of Russian capabilities and refinement of processes. The Russians are not the only nation reorganizing and investing heavily in the ability to control the EMS.

China

The Chinese, the PLA specifically, have reorganized to integrate EW technologies and capabilities designed to deny the US use and advantage in the EMS. Although literature on this topic is sparse at the unclassified level, a 2015 DoD report to congress highlights advances in Chinese space capabilities designed to challenge adversary use of space-based systems. The report states "China continues to develop a variety of capabilities designed to limit or prevent the use of space-based assets by adversaries during crisis or conflict including the development of directed-energy weapons and satellite jammers."[15] Although the report does not identify specific systems or capabilities, it does highlight Chinese military academy writings which emphasize "destroying, damaging, and interfering with enemy's reconnaissance… and communications satellites" implying that such systems do exist, and that US communications and ISR satellites could be targets for attack. This is further supported by 2018 Article from Janes Weekly, which indicates China is investing substantial resources into initiatives focused on improving network and electronic warfare capabilities, to include, ground-based sensors and jammers, space-based intelligence assets, and airborne jammers.[16] Without substantial information on system capabilities, analysis of PLA military organizations and methodology of warfare can provide insight into how the Chinese intend to leverage the EME in conflict as well as combat.

The Strategic Support Force (SSF) coupled with the doctrine systems destruction theory, provide China the organization, forces, and doctrine to gain EMS superiority in a contested environment. The creation of the SSF in 2015 signifies an important shift in the PLA's prioritization of information warfare. A 2017 RAND report assesses "the SSF has been charged with developing and employing space, cyber, and electronic warfare capabilities… by providing operational commands with information-warfare infrastructure necessary to conduct "informatized local wars."[17] By conducting this organizational restructure, the PLA has created a "functional combatant command-like" organization which can act independently, or in support of PLA services. This construct more adequately supports the system integration of counter-space, cyber, and EW systems against an adversary threat. National level EW capabilities fall under the SSF in the Network Systems Department, responsible for jamming satellite communications, GPS signals, as well as cyber-attacks against space related infrastructure. These capabilities are designed to provide an asymmetric advantage to the PLA during conflict in the EME. Because the US Military relies heavily on space-based communications and ISR utilizing the EMS, the SSF demonstrates the PLA's priority on influencing ground and satellite-based users of the EMS. Of equal importance to the SFF's capabilities are the methodology in which those capabilities will be employed.

Understanding how the Chinese PLA intends to compete with adversaries offers insights into how it may use its systems to contest the EMS during conflict. One such concept is "informationized warfare" in which China gains advantage over an adversary through information dominance while denying the adversary's ability command and control their own forces.[18] A second central theme is the PLA perception of modern military conflict to be a confrontation between opposing systems. This is a departure from the traditional understanding of conflict between units, arms, services, or weapons. This broader understanding recognizes the contest between numerous operational systems, referred to by the Chinese as systems confrontation, system on system warfare.[19] It is critical for US military professionals to identify and understand this key conceptual difference in thought. In the Chinese view, conflict no longer occurs in the traditional physical domains of land, sea and air but also in outer-space, nonphysical cyberspace, and the electromagnetic spectrum. The PLA's current theory of victory is based on system confrontation and system destruction warfare, which seeks to paralyze or destroy critical functions of an adversary's operational system. According to this theory, the adversary loses the ability to resist once its operational system is paralyzed or ceases to function. PLA literature reinforces and narrows the scope of these critical functions to include command and control, reconnaissance, intelligence, and firepower capabilities. Degrading these capabilities significantly disrupts the flow of information within the

adversary's operational system. An introspective look at US military operations reveals a significant reliance on the EMS to conduct the above functions.

Shortfalls in Policy Implementation.

Service Policy and Concepts Since 2010

Current service policy for Electronic Warfare dating from June 2011 acknowledges MAGTF operations are conducted in an "increasingly complex electromagnetic environment." It also highlights "the ability to exploit and control the electromagnetic spectrum, at the time and place of the Commander's choosing is critical to the success of the MAGTF throughout the full range of military operations."[20] The policy goes on to say that "in order to retain the freedom of maneuver in the EMS, the MAGTF must contain an organic mixture of ground and airborne EW capabilities able to support stand-alone MAGTF operations." While EW policy provides the necessary guidance to the force in prioritizing the importance of EW, over a decade since the its publishing, the force still lacks the equipment and training required effectively implement the policy in the scale required by a peer competitor.

In March of 2017 the Marine Corps published a strategy for assured command and control. In this document, then Commandant of the Marine Corps, General Robert Neller, asserts that maintaining a secure, adaptable, and innovative C2 environment ensures, "we preserve a decisive advantage over our adversaries".[21] The Commandant goes on to highlight four key characteristics the command and control environment/ network must possess to be effective in the future operating environment: unified, resilient, interoperable, and expeditionary. The primary vision set forth in the document espouses an assured enterprise warfighting network allowing timely and persistent information exchange in the most demanding environment and circumstances realized through efficient and responsible stewardship. This vision statement is unnecessarily vague and points to efficient and responsible stewardship as the primary means by which information is to be exchanged in "the most complex and demanding environments."

The vision stated above is supported by a number of goals. The most important of these goals is to "transform marine air ground task force command and control: Establish a warfighting network providing interoperable, ubiquitous, and rapid access to information in any environment."[22] This goal is lofty and highly inspirational, although it should still be referenced as a source of change throughout the marine corps communications enterprise. This goal is valuable in the sense that it establishes the initial momentum for change and provides basic focus areas in which that change should occur. Interoperability and rapid access to information are key characteristics of a command and control network, however, these characteristics beg the question of what happens when commanders do not have rapid access to information? And how are these commanders ensuring their access to information by protecting the critical segments of the EMS required for military communications?

There are a number of supporting objectives nested within the goal of transforming the MAGTF command and control. The most notable of which are Command and Control Diversity/ network survivability. The realization that the Marine Corps is over reliant on satellite-based communications, making communications networks vulnerable, and a high-value target to adversaries is a given when aligned against capabilities currently employed by peer competitors. Investments in line of sight and advanced beyond line of sight technologies, as well as the training to employ those technologies, will be critical for success in the future environment.

Noticeably absent from this document is mention of the ability to sense and understand the EMS or to engage the EMS as maneuver space. Much of what is discussed in the document relates to the enterprise and high-level policy and organizational bureaucratic management, while leaving a gap between the overarching policy and the operational and tactical level where capabilities are required to inform higher levels of command. Moreover, "assured communications" implies a method to transfer the information to the people or agency that needs it in a timely manner, regardless of the environmental situation. This strategy does not provide the level of information or guidance necessary for "assured communications" at the tactical or operational level.

To further reinforce the importance of the EMS in modern conflict, the US Marine Corps published the Marine Corps Concept for Electromagnetic Spectrum Operations in October of 2017. This concept provides an outline for how the Marine Corps seeks to sense, understand, exploit, and attack in and through the Electromagnetic Environment (EME).[23] In the forward of the document, Lieutenant General Walsh exerts that "the MAGTF must develop and implement a comprehensive and integrated approach to sensing, understanding, and maneuvering in and through the EMS to support the achievement of MAGTF objectives." The concept as presented throughout the document provides a comprehensive overview of the EME, EMSO capability areas, MAGTF organizations reliant on EMSO and Risks associated with the EMSO concept.

Although the EMSO concept clearly highlights the importance on EMSO in supporting the MAGTF, the concept cannot be achieved due to shortfalls in equipment, training. While the EMSO concept lists a number of required capabilities to adequately employ the concept as described, few if any of these capabilities have actually reached the operating forces.

Throughout the EMSO concept, a reoccurring paradox is highlighted. The notion that MAGTF commanders and staff must have continuous access to information in order to make decisions directly conflicts with the idea that the EME will be contested and the MAGTF commander and staff must be comfortable and equipped to effectively conduct operations in the absence of real-time information about the location and disposition of friendly and enemy forces. The concept inadequately addresses this issue by stating "information collected, shared, and processed from disparate systems are essential to the synchronization of EMSO, and the loss of connectivity will have adverse impacts on operations."[24] The take-away from the EMSO concept is that the MAGTF is even more reliant on the EMS to conduct MAGTF operations than it is equipped to protect its use of the EMS. The degree to which the MAGTF relies on real-time information about the EME identifies a key vulnerability in current MAGTF operations.

Recognizing the Gaps in Training

The Marine Corps is taking steps to increase its level of awareness of what it means to fight a modern competitor. In January of 2020, 2d Marine Division participated in MAGTF Warfighting Exercise 1-20 in Twentynine Palms, California. The exercise simulated the initial stages of a conventional conflict with a peer competitor in the European theater. 2d Marine Division, with organic and attached logistics and aviation combat elements simulating force on force engagements with a thinking enemy comprised of 7th Marine Regiment and 800 British Royal Commandos. The exercise evaluated 2d Marine Division's ability to "fight tonight," with the mission to "Enhance the commanding general, staff, and subordinate commander's cognitive ability to sense, make sense and take action in a time competitive, domain disadvantaged environment."[25] The lessons learned from this exercise reinforce the notion that the Marine Corps as an organization is not prepared to use the EMS as maneuver space, nor is it equipped to adequately defend the spectrum.

The nature of the enemy threat forced 2d Marine Division to fight a "battle of signatures" due to the nature of the adversary ISR capabilities. In a discussion at USMC Command and Staff College, Major General Furness highlighted the several command and control considerations and current capability shortfalls brought out during the exercise. Highlights include outdated command and control systems, the need for burst transmissions, and LPI/LPD waveforms.

The exercise highlighted outdated command and control systems, and a command and control philosophy which is centered around voice transmissions as the primary means to transmit information at the tactical level. Marine Corps communications systems and equipment are designed to remain operational for long periods of time making them susceptible to adversary ISR. The equipment is also not durable enough to be set-up and taken down multiple times a day for the duration of an operation or exercise. Voice communications requires a radio operator to transmit RF energy for the duration of the transmission, it also requires the station receiving this information to confirm they received and understood the transmission, also requiring transmission of RF energy. These RF transmissions create a signature which can be rapidly identified and targeted. A viable solution to the reliance on voice

communication is burst data transmission where messages are sent via data text as opposed to voice. A simple analogy can be made to using a commercial cell phone to text information instead of making a phone call to convey the same information.

EW training restrictions and regulatory processes stifle the effectiveness training when it does take place. Lengthy coordination timelines and strict FCC and FAA rules on who can transmit and on what frequencies inside the United States limit the effectiveness of EW training.[26] The proximity of major marine corps training facilities in close to major commercial airline routes and metropolitan centers further restricts the power and duration EW systems can be used. The power of military EW systems and shared use of the spectrum for commercial applications such as wireless phones and mobile phones, means that existing equipment is often only allowed to be used at a reduced power setting.[27] Because of these limitations, EW units are often limited to classroom training or computer based academic training to maintain proficiency between major pre-deployment exercises.[28]Doing this dilutes the realism of the training and does not portray an accurate representation of the EW systems the military may see in conflict.

Cultural bias in military training exercises also plays a role in the effectiveness of the training. Often, operating in a contested EMS environment is only one item on a long list of requirements for military units to conduct during training. Although EW provides a more realistic environment to train in, if the EW effects impact other aspects of the training exercise, EW units are often told to stop jamming in so other tasks can be accomplished.[29] reduces the effectiveness of the other aspects of training. . Consequencys

Recognizing the Gaps in Equipment

Despite existing policy recognizing key capability gaps in sensing and contesting the EMS, the Marine Corps has yet to field the breadth and depth of equipment necessary to match adversary capabilities. An October 2018 Marine Corps Gazette article *Spectrum Warfare Integration*, authored by Marine Electronic Warfare Officer, brings to light the woeful inadequacies of the Marine Corps Electronic Warfare capability.[30] The author states that "the United States Marine Corps is woefully unprepared for conflict in a spectrum-degraded environment, and we lack the capability to conduct electronic warfare (EW) in any significant way." He highlights Marine Corps Order 3430.2C, Marine Corps Policy on Electronic Warfare, signed in June 2011, which provides guidance to the force on how EW should be incorporated throughout the Marine Corps. Seven years later, the author's assessment is that the Marine Corps "has failed as an institution" to reach any of the goals established in the document. The author goes on to highlight that EW systems are limited in quantity and tactics, techniques, and procedures are still in development to determine capabilities and limitations as well as the best methods for operational employment. Additionally, the personnel assigned to conduct EW operations, the EW support teams are not plentiful enough to provide support throughout the force.

A Congressional Research Service (CRS) report from 2019 identifies limited numbers of ground based Electronic Warfare capabilities for the U.S. military. The report defines Electronic Warfare by referencing the Department of Defense definition of "military action involving the use of electromagnetic and directed energy to control the electromagnetic spectrum or attack the enemy." The report identifies that ground based EW systems are primarily focused on countering Unmanned Aerial Systems (UAS) or Improvised Explosive Devices (IEDs), only a small number of systems area available to detect or jam communications in the EMS. The U.S. Marine Corps in particular only has two programs of record available to conduct ground-based EW. The AN/MLQ-36 Mobile Electronic Warfare Support System (MEWSS) provides mobile detection and jamming capabilities to the USMC Radio Battalion, however there are only 12 systems throughout the Marine Corps, four per battalion. The Communications Emitter Sensing and Attack System (CESAS) II, has the ability to conduct sensing and jamming in a broader range of the EMS, from HF to UHF. Although a significant capability in the EW fight, the CESAS II is not prevalent enough in the Marine Corps inventory to have a significant impact across the force. These high demand, low density items are often forward deployed and not available for training. To put these capabilities in perspective, when comparing the ground order of battle, one Russian motorized rifle

Brigade has roughly 100 personnel and equipment to jam every frequency range of Marine Corps communications and radar systems. Marine Infantry regiments do not have any organic EW systems of any kind. Moreover, the Marine Expeditionary Force (MEF), a general officer level headquarters, is the lowest echelon where ground EW equipment resides in the service. Although equipment and personnel is allocated to more tactical units for deployments and training, the lack of organic EW equipment at the regimental level and below presents a clear gap in capability.

Despite a relatively bleak outlook from the operating forces, the Marine Corps is taking steps to improve its ability to understand and compete in a contested EMS. Significant indicators of this is are the inclusion of EMSO in recent service level exercises, involvement of the Marine Corps Warfighting Laboratory in developing EW equipment and software to enable EMSO and wargaming efforts which incorporate EMSO and EMS planning into wargaming scenarios.

The Way Forward – Improving implementation of EMSO Concepts and Strategy

Training

Realizing that equipment development, testing and acquisition is a lengthy process, there are near term implementation measures available to prepare forces for conflict in the EMS. One such measure is include digital wargaming into existing training opportunities. By including EMSO wargaming into current training scenarios, Marines will have greater exposure to planning and conducting operations in a synthetic environment, reducing the need for high-demand, low density EW equipment or exquisite training facilities. Additionally, the EMSO environment allows for the assessment of current and future capabilities paired against peer adversary capabilities. This assessment should identify strengths and shortcomings of current and future systems, equipment, and organizational practices. Additionally, these assessments can provide valuable data to inform future force design as well as acquisitions strategies in order to provide the force with the necessary equipment to fight effectively against peer adversaries. These measures are not meant to replace real world training, they are only meant to augment and support training when access to equipment, facilities, and adversary forces are unavailable.

A primary challenge in preparing for future conflict in the EMS is most Marines have never experienced a denied or degraded EMS environment, and therefore have little understanding of how such an environment can impact military operations. Providing this experience in a virtual environment can effectively educate Marines to the importance of the EMS, as well as, provide “reps and sets” for commanders to effectively maneuver and fight in and through the EMS.

Equipment capabilities for C4ISR and EW related systems should be tested during wargaming scenarios. It is important to examine both friendly and adversary equipment capabilities in this method for two reasons. First, friendly C4ISR and EW systems can be evaluated against realistic adversary systems. It is critical to understand if current Marine Corps C2, ISR and EW equipment has the correct spectrum flexibility as well as power output to be effective against adversary systems. Doing this also exposes gaps in adversary coverage of the EMS. Secondly, evaluating capabilities in this manner provides Marines with experience incorporating these systems in a training environment where propagation modeling and simulation can inform best practices and procedures for employment. For example, if a peer adversary relies on High Frequency and Very High Frequency (VHF) communications for the majority of their tactical level command and control, friendly jamming equipment should match the frequency spectrum of adversary capability to jam in the HF and VHF spectrum over other frequency bands. These wargames can inform where friendly systems can achieve overmatch in a particular frequency band or where friendly equipment have superior characteristics (range, power, spectrum diversity) which can negate enemy capabilities.

Understanding the practices of employment for system and equipment capabilities, is just as important as understanding the systems and capabilities themselves. Wargaming allows existing equipment and systems to be used in different ways to achieve superior results on the battlefield. For example, if during wargaming it is determined that friendly radio equipment operated at the highest power setting, can be detected by adversary EW or ISR assets, it can be determined what the optimal radio

power setting is for achieving necessary communications while reducing the ability to be detected by adversary equipment. Methods of employment can also be tested during this type of wargaming. For instance, the survivability of large, immobile command and control centers such as the Marine Corps CAPSET Combat Operations Center can be tested against adversary threats. This information can be used to develop more mobile, modular, and survivable command and control centers with the necessary array of decoys and spectrum situational awareness tools to remain effective and survivable against peer threats. Other employment methods relevant to current operations are the use of receive only communications systems such as the Global Broadcast System (GBS). The system provides high-bandwidth, receive only capability, capable of streaming ISR full motion video, as well as download large imagery files and common operational picture tracking information.[31] Because the system only receives RF energy and does not broadcast any RF energy, it is possible for friendly units to avoid using a high-power SATCOM terminal that can be easily detected by adversary EW systems. Wargaming also provides the ability to test developmental concepts in a threat environment. These concepts include the use of communication repeaters on unmanned vehicles (on both airborne and surface vehicles) and high-altitude balloons for long range communications. A common argument when discussing distributed operations is the ability of small, distributed units to remain below the targeting threshold of adversary ISR and threat assessments. Wargaming these types of forces, with current and future equipment and systems capabilities can provide a valuable assessment and learning tool for leaders to prepare for future conflict.

Integration with US Navy EW and EMSO capabilities provides opportunities for the marine corps to address shortcomings in organic EW systems and increase naval service integration. As part of the broader naval service, integration with US Naval EW platforms offers opportunities to leverage greater EW capabilities for both training and real-world operations. Understanding naval EW system capabilities can provide opportunities for marine corps integration while provided increased capability to the maritime force. This integration also provides the opportunity to develop joint doctrine by standardizing service processes and procedures. This collaboration should also extend to EMSO visualization software and information processing equipment. Ensuring compatibility in this process will reduce the familiarization required during conflict and synergize the naval services.

Illustrative Case Study

A case study is a research methodology used to examine in depth to provide a basis for understanding the wider application of this technology. Research involved first hand participation in a wargame scenario which applies EMS visualization software into tactical level military wargaming. The intent of this participation is to evaluate the effectiveness of data visualization software when applied to the EMS environment. The second case study involves the examination of a Marine infantry battalion subjected to intense EMS interference during EXERCISE SOLID SHIELD in 1976. This historical case study evaluates the effectiveness of tactical leaders in a contested EMS after adequately preparing for engagement in that environment.

Sea Dragon 2019

Marine Corps University's collaboration with DARPA during the 2019 Sea Dragon wargame provides a valuable model of how EMSO can be incorporated into future wargaming efforts. The Sea Dragon competition is an annual wargaming/ planning competition run by the Marine Corps University where students participate in futuristic force on force scenarios. DARPA provided a synthetic environment and automated planning capability being developed by DARPA's Prototype Resilient Operations Testbed for Expeditionary Urban Scenarios, or PROTEUS program. During this year's competition, participants experienced simulated, tactical level, multi-domain warfare. The wargame scenario featured advanced EW and EMSO planning tools and manned/ unmanned teaming with diverse ISR and sensor capabilities.

The results of the wargame showed that increasing the number of unmanned systems at the tactical level tended to overwhelm small or inexperienced command teams. Simultaneously manipulating multiple UAVs required spectrum awareness to ensure UAVs maintained communications links to supported units. Accounting for terrain, adversary EW capabilities, and UAV range limitations added additional complexity that inexperienced participants were unable to handle. Additionally, few players possessed experience in compensating for an adversary equipped with EW capabilities. This unfamiliarity caused tension when players realized they were unable to communicate with friendly forces that were being actively jammed by the adversary. Although this conclusion seems straightforward, the expectation of assured communications, regardless of enemy capabilities, highlights a common bias among mid-career officers whose only operational experience is in uncontested EMS environments.

Most participants did not have experience visualizing spectrum management and thinking in terms of connectivity to their units, signal strength, and emissions control. Familiarity with the EMS proved to be beneficial to teams with participants familiar in communications planning or electronic warfare. The relatively simple visual display and planning parameters often overwhelmed participants. These teams resorted to conventional tactics that were ineffective against participants leveraging the full capability of the software.[32] The software provided players with enhanced decision-making information, allowing for optimum communications capability in which software augments human decision making. A significant benefit of the wargaming software is the ability to visually display the EMS in real time as the forces in play maneuver throughout the battle space, experiencing contested and uncontested spectrum as a natural factor in the environment.

Clear take-aways from the Sea Dragon 2019 wargame are two-fold. First, planning and operational experience in a contested EMS environment is lacking in mid-career Marine Corps officers. Wargaming provides a cognitive replacement for operational experience by simulating the same conditions one could experience in real world operations and forces decision makers to adjust their thought process and decision making accordingly. Secondly, software applications which visually display EMS information significantly increase the understanding of the environment for those unfamiliar with EMS operations. DARPA's PROTEUS program provided the visualization necessary to effectively understand and conceptualize the EMS environment.

Exercise Solid Shield

A historical success story of Marine Corps operations in a contested EME can be found in analyzing the performance of 2d Battalion, 8th Marines during Joint Training Exercise SOLID SHIELD during the summer of 1976. Of all of the services involved in the exercise, Marine Corps forces were subjected to the most intense EW, in terms of both quantity of systems operating against them and the intensity of the jamming.[33] Having trained to understand and operate in a jamming environment, 2/8 was prepared for the intense jamming it received during the exercise.

Tactical commanders understood the ECCM procedures required to operate effectively in a contested EME. Their identification of the contested EMS and subsequent transition to alternate means of communication was described as being "virtually flawless." A specific example of this understanding occurred when the battalion conducted a heliborne assault during a period of significant EW jamming. Upon entering the landing zone, the company commander of the initial unit in the landing zone recognized the jamming and informed all personnel they were receiving jamming. Simultaneously, the commander had a Meaconing, Intrusion, Jamming, and Interference (MIJI) report prepared for later transmission when the unit was out of the jamming environment. Next, the commander directed messengers to be used for communications between company and platoon elements. He instructed other companies to do the same, and only have the actual company commanders use the radio because voice identification of the other commanders would negate the intrusive deception techniques being used against them. Identification tables were also used effectively to mitigate the imitative effects of adversary deception efforts. Throughout the four and a half hours of jamming, the battalion successfully consolidated, defended their position and moved from the area to their link up position using only hand

signals, runners, and radios at close range. This vignette demonstrates the flexibility and adaptiveness required of small units' leaders in contested EMEs. Additionally, the scenario demonstrates the effectiveness of training to operate in a contested EME.

Equipping the Force.

Although any unit with communications equipment such as radios, GPS receivers, and SATCOM terminals may be able to identify interference within the EMS, units below the MEF level do not have the organic equipment or training to identify interference in any meaningful way. Dedicated spectrum management software or equipment is not available below the Major Subordinate Element (MSE), the Marine Division, Logistics Group, and Aviation Wing level of command. The individuals responsible for spectrum management reside within the MSE Staff. Radio Battalions, under command of the MEF Information Group, can task organize Electronic Warfare Support Teams (EWST) capable of conducting EW functions, but these teams are not organic to units below the MEF level. These units provide limited EW capability when employed. In order to be effective EWSTs must be assigned to lower echelon units provide meaningful EW contributions in support of the MAGTF. In an EABO concept, notionally, each forward deployed site would require the capabilities of an EWST. In a distributed construct, the Radio Battalion quickly exhausts its ability to source EWSTs with equipment and personnel. Equipping tactical units with Free Space Optics, GBS, and advanced software applications provides a reduced the RF signature and increases the EMS situational awareness.

Free Space Optics (FSO) relies on light-based laser instead of radio frequencies to transmit data. By relying on light to transmit information, this system negates radio frequency detection and jamming threats associated with the radio frequency spectrum. Advances in Free Space Optical technology or light-based communications have allowed for high data rate, long distance communications both on the surface and below the water.[34] The Marine Corps is already experimenting with this technology, and will need to implement this technology in place of existing microwave radio systems.[35] This type of communications does not rely on the radio transmissions, which makes it ideal for long distance, point to point communications in a contested electromagnetic spectrum environment. Advances in technology have mitigated the effects of atmospheric diffraction allowing for effective transmissions in humid climates. The Marine Corps should continue to experiment and expand this capability with the U.S. Navy to provide a robust fiber like capability throughout the littoral environment to support distributed operations.

The GBS is a second capability that is currently fielded, but underutilized by the Marine Corps. GBS provides downlink only, high bandwidth communications, allowing large files and high data-rate communications to be sent to users who to do have access to developed infrastructure. By proliferating the GBS system down to the tactical level, subordinate commanders under the MLR and MEU can maintain accurate situational awareness and access national and theater level intelligence products while maintaining a passive electronic signature. The Suitcase Portable Receive Suite (AN/PRS-11) is a lightweight, man packable system currently used by special operations teams to access full motion video feeds, and receive large data files such as intelligence updates and geospatial intelligence information.[36] This capability also allows a Marines commander to access the joint Common Operational Picture (COP) in a real time manner without maintaining continuous communications and compromising the electronic signature of the friendly force position.

If the electromagnetic spectrum is considered to be "maneuver space" Marines need the ability to sense the electromagnetic environment in order to understand if they are being jammed, transmit on unjammed frequencies. Additionally, this understanding of the electromagnetic environment allows a Marine element to blend into the natural electromagnetic environment in order to avoid detection. Currently, there are no electromagnetic spectrum monitoring systems employed below the regimental level. Software defined radios combined with software such as RadioMap, a mobile spectrum

management software application provide a viable solution to mitigate this issue.[37] Although still in the testing phase, this software, or software like it, will allow Marines to understand the nature of the EMS environment and adapt to their environment.

Policy Recommendations

Improvements in service acquisition policy and federal regulations regarding EW training will improve the EW posture of the Marine Corps. Current acquisition policy

Conclusion.

The Marine Corps can effectively implement actions to maintain communications resiliency and reduce reliance on the EMS through aggressive wargaming and equipment investments. Prioritizing contested EMS environments in wargaming scenarios, provides the Marine Corps with the next generation of leaders and decision makers familiar with utilizing the EMS as maneuver space. These efforts also allow the service to test existing and future capabilities against threat capabilities to develop effective techniques for employment, should conflict arise. An emphasis on EMS vulnerabilities and mitigation strategies should continue to be included in all service level exercises and pre-deployment training exercises. These efforts will further inform acquisition strategies to provide the Martine Corps with EW equipment capable of protecting and denying the EMS to peer and near-peer adversaries.

The Marine Corps can provide resiliency to current communications systems through the increased fielding of FSO transmission systems, Global Broadcast Systems, and EMS visualization software. FSO transmission systems should be incorporated down to the infantry battalion level to facilitate high bandwidth data transfer capabilities. This technology, coupled with small form factor GBS receivers such as the AN/PRS-11 offer high-bandwidth transmission capabilities without continuous reliance on radio frequency portion of the EMS, thereby increasing resiliency in tactical communications systems. Sensing and visualizing the EMS through software applications such as RadioMap provide greater situational awareness for commanders and senior decision makers. Although RadioMap is still in testing and development, continued investment in this type of technology is critical for the service to be able to maneuver in the EMS.

The Marine Corps must prepare to conduct operations in a contested EMS environment. Command and control, force protection, movement and maneuver, intelligence, information, fires, and sustainment functions rely on access to the EMS independently and to be effectively integrated into a cohesive warfighting construct. In the context of great power competition and potential great power conflict, adversary capabilities to deny the US Marine Corps use of the EMS vastly outweigh the ability of the service to protect its use of the spectrum. Russian reorganization to incorporate organic EW capabilities with tactical infantry units and modernization of strategic EW capabilities demonstrates the importance of supremacy in the EMS. Additionally, the PLA's establishment of the Strategic Support Force coupled with doctrine focused on denying adversaries access to information and degrading information related capabilities highlight their perceived importance of the EMS. If faced with a conflict with a peer competitor, the Marine Corps risks being forced to operate in an environment it is neither equipped or trained for. Despite years of policy directives and concept development and implementation, the service continues to be severely limited in its ability to operate within a contested EMS. By incorporating DARPA's PROTEUS program into future wargaming efforts, the Marine Corps will dramatically increase Marines understanding of operating in contested EMS environments. Additional equipment procurement in free space optics, the Global Broadcast System, and EMS monitoring software will provide the Marine Corps the necessary capabilities to remain competitive with peer and near-peer adversaries in the EMS environment.

Individual study and familiarity with the future operating environment are the first steps in supporting the institutional change called for in this document. As military professionals and leaders, it is our duty to analyze the challenges presented by potential adversaries, educate those within our sphere of influence, and share this understanding. The research involved in this process serves as education for the

broader community of military officers and communications professionals and as a platform to continue this discussion.

Notes

[1] US Department of Defense. Summary of the 2018 National Defense Strategy of the United States of America: Sharpening the American Military's competitive Edge. (Washington, DC: US Department of Defense, 2018),
[2] Department of Defense. Joint Electromagnetic Spectrum Operations. Joint Doctrine Note 3-16. Washington, D.C, 20 Oct 2016
[3] CRS Report to Congress. IF11155. Version 4. 30 December 2019.
[4] US Marine Corps. Marine Corps Concept for Electromagnetic Spectrum Operations. 18 Oct 2017. Quantico, VA
[5] US Department of Defense. Joint Publication 1-02: Department of Defense Dictionary of Military and Associated Terms. Washington, DC, 8 November 2010. 82
[6] US Army Heritage Foundation. Keeping the Lines Open: The United States Army Signal Corps. Accessed January 15, 2020, https://www.armyheritage.org/75-information/soldier-stories/283-signalcorps
[7] ***Source in Excel Doc.
[8] Figure Citation
[9] Joseph Trevithick, "American General Says 'Adversaries' Are Jamming AC-130 Gunships in Syria," _The Drive, April 25. 2018, https://www.thedrive.com/the-war-zone/20404/american-general- says-adversaries-are-jamming-ac-130-gunships-in-syria.
[10] https://thehill.com/policy/defense/416625-nato-russia-jammed-gps-signals-during-exercise-with-us-troops
[11] US Marine Corps. *Future Operating Environment 2015-2025*. Marine Corps Intelligence Activity. Quantico, VA. 2019
[12] John R. Hoehn. Ground Electronic Warfare: Background and Issues for Congress. (Washington, D.C.: Congressional Research Service, September 17, 2019), R45919, 14.
[13] Ibid.
[14] Roger N. McDermott. *Russia's Electronic Warfare Capabilities to 2025: Challenging NATO in the Electromagnetic Spectrum*, (Essti, Estonia: International Centre for Defense and Security, September 2017), 14, https://icds.ee/wp-content/uploads/2018/ICDS_Report_Russias_Electronic_Warfare_to_2025.pdf
[15] US Department of Defense. Annual Report to Congress: Military and Security Developments Involving the People's Republic of China 2019 (Washington, DC: Office of the Secretary of Defense, 2019)
[16] Tate Nurkin, Kelly Bedard, James, Clad. China's Advanced Weapons Systems, HIS Janes, May 2018, https://www.uscc.gov/sites/default/files/Research/Jane%27s%20by%20IHS%20Markit_China%27s%20Advanced%20Weapons%20Systems.pdf
[17] Kevin L. Pollpeter, Michael S Chase, Eric Heginbotham. *The Creation of the PLA Strategic Support Force and Its Implications for Chinese Military Space Operations*, (Santa Monica, CA: RAND corporation, 2017). 1
[18] John R. Hoehn. Ground Electronic Warfare: Background and Issues for Congress. (Washington, D.C.: Congressional Research Service, September 17, 2019), R45919, 14.
[19] Jeffery Engstrom. *Systems Confrontation and System Destruction Warfare: How the Chinese People's Liberation Army seeks to Wage Modern Warfare, (*Santa Monica, CA: RAND corporation, 2018). x
[20] US Marine Corps. Marine Corps Order 3420.2C: Policy for Electronic Warfare. Headquarters United States Marines Corps, 7 July 2011, Washington, DC.
[21] US Marine Corps. Marine Corps Strategy for Assured Command and Control. March, 2017. Quantico, VA. ii
[22] Ibid. 9
[23] US Marine Corps. Marine Corps Concept for Electromagnetic Spectrum Operations. 18 Oct 2017. Quantico, VA. 2
[24] Ibid. 16.
[25] Furness Major General, After Action Review of MAGTF Warfighting Exercise 1-20.
[26] Sydney J. Freedberg Jr. US Forces Untrained, Unready for Russian, Chinese Jamming. 30 October, 2019. Accessed 25 March 2020. https://breakingdefense.com/2019/10/us-forces-untrained-not-ready-for-russian-jamming/
[27] Ibid.

[28] Bryan Clark, Whitney Morgan McNarara, Timothy Walton. Winning the Invisible War: Gaining an Enduring U.S. Advantage in the Electromagnetic Spectrum. Center for Strategic and Budgetary Assessments. 24
[29] Ibid. https://breakingdefense.com/2019/10/us-forces-untrained-not-ready-for-russian-jamming/

[30] Jonathan M. George. *Spectrum Warfare Integration: Regaining dominance of the spectrum*. Marine Corps Gazette, Quantico, Va, May 2019.
[31] USMC. Concepts and Programs, Modernization and Technology, Information Operations, Command and Control: Global Broadcast System. Quantico, VA, 2019. https://www.candp.marines.mil/Programs/Focus-Area-4-Modernization-Technology/Part-2-Information-Operations/Part-21-Command-and-Control-C2/GBS/
[32] Ben Jensen and John Paschkewitz. *Mosaic Warfare: Small and scalable are beautiful*. War on the Rocks. 23 December, 2019. https://warontherocks.com/2019/12/mosaic-warfare-small-and-scalable-are-beautiful/

[33] US Marine Corps. OH 3-4. Electronic Warfare Operations Handbook. Marine Corps development and education command. Quantico, Va. 101
[34] Gwen Weerts, "Free Space Optical Communication Takes a Deep Dive. *SPIE*. 1 July 2019. https://spie.org/news/spie-professional-magazine-archive/2019-july/free-space-optical-communication-takes-a-deep-dive?SSO=1
[35] Todd South. "From high-tech lasers to old school wire, MarinesMari test both ends of the communications spectrum." Marine Corps Times Online, 29 August 2018. https://www.marinecorpstimes.com/news/your-marine-corps/2018/08/29/from-high-tech-lasers-to-old-school-wire-marines-test-both-ends-of-communications-spectrum/
[36] US Marine Corps Concepts and Programs, Information Environment operations, Command and Control, Global Broadcast Service. https://www.candp.marines.mil/Programs/Focus-Area-4-Modernization-Technology/Part-2-Information-Operations/Part-21-Command-and-Control-C2/GBS/
[37] Kimberly Underwood, "Mobile Spectrum Tool RadioMap moves to the Marines." *SIGNAL*, August 2018 https://www.afcea.org/content/mobile-spectrum-tool-radiomap-moves-marines