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14. ABSTRACT

Radiofrequency Weapons could revolutionize warfare by denying the use of advanced electronic systems that modern militaries have become reliant upon for nearly all functions of warfare. RF weapons could disrupt and destroy computer-processing units onboard hi-tech cruise missiles, fire control radars on ships, electro-optical sensors, and sensitive electronics found on state-of-the-art fighters and bombers—all at the speed of light. The U.S. Navy's surface and subsurface platforms need an over-the-horizon radiofrequency weapon in order to disrupt adversary decision-making and deny the adversary's mission capability by degrading or destroying critical electronic systems at extended ranges.

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RF Weapon Delivery From Naval Platforms

by

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A paper submitted to the Faculty of the Naval War College in partial satisfaction of the requirements of the Gravely Advanced Research Program.

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Signature: _____

28 May 2018

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The Following Vignette is not based on real events, and represents only a theoretical scenario to illustrate the potential capabilities of a future concept presented by the author.

"The difference between a good officer and a bad one is about 10 seconds."[1]
-Admiral Arleigh Burke

A surface force has been detached from the strike group to position northwest of Taiwan to protect the approaches to the carrier operating areas (CVOA). The disaggregated force, a surface action group (SAG) commanded by USS COWPENS (CG 62) is comprised of USS CURTIS WILBUR (DDG 54) and USS MILIUS (DDG 69). The SAG had been operating on station for three days, when without warning all communications to the Strike Group were lost. Unbeknownst to the SAG on patrol, the People's Republic of China successfully detonated an EMP over Taiwan that affected the CSG's over-the-horizon communications as well, effectively striking the first blow in the RF spectrum. While each ship had exercised and trained for this very scenario, the reality was far more intense and disorienting. The SAG-C directed his units to maintain visual range. The world's most technologically advanced Navy was reduced to flag hoist and semaphore. The ships' Demand Assigned Multiple Access (DAMA) systems continued to fail to synchronize. Only several hours later were the ships able to re-establish secure line of sight voice communications, but still had not regained communications to the strike group. The SAG Commander directed all units under tactical control (TACON) to continue on the last orders received with the rules of engagement (ROE) and permissions already in place to find and neutralize PRC surface critical contacts of interest (CCOI). Suddenly, USS MILIUS (DDG 69) reports at least two supersonic contacts on her SPY-1D

[1] "Ten Seconds." USNI Blog. April 07, 2016. Accessed May 11, 2018. https://blog.usni.org/posts/2016/03/23/ten-seconds.

radar with no additional identifying information screaming toward their position. She immediately launches a salvo of standard missiles to engage the incoming missiles. The SAG had been located, and the enemy had struck first.

All ships in the SAG launched countermeasures in accordance with pre-planned responses and braced for impact. One SM-2 successfully engaged, littering CURTIS WILBUR tactical action officer's (TAO) Command and Decision (C&D) screen with false contacts from the debris particle raining down from the atmosphere to the wave tops. The second missile continued to scream in. It was USS MILIUS (DDG 69) that was able to identify the radar signature as a YJ-18. There was a RENHAI somewhere over the horizon, and there was no question, the PRC had the SAG zeroed in…

Fifteen minutes earlier, to the west, USS VIRGINIA (SSN-774) operated at periscope depth, fighting the sea state and a denied EM environment to establish communications to CTF-74 and report her probable kill of one SHANG II and one SONG class SS since the last comms window. The boat's captain began to lose his patience with his radio room as they continued to wait for the communications to synchronize. Suddenly, the high-tech submarine's officer-of-the-deck (OOD) requested the captain to the Conn, a rare request from his most seasoned department head on board. VIRGINIA had acoustic contact at extended ranges of a Chinese carrier and at least four warships. In accordance with the guidance provided from CTF-74 during his meeting with the Admiral, the boat's CO was to take early and decisive action to disrupt and deny the adversary's attempts to establish sea control. "Deploy the mindbender," ordered the skipper. It was too bad he wouldn't be able to stick around to see what this weapon could do, but staying up at periscope depth was too risky.

The UAV launched swiftly on its one way mission with a whoosh, climbing into the air and quickly out of sight. The OOD, now swiveling the periscope with his video game-like controller, conducted one last look for possible reaction and ordered the submarine deep. Back above the surface and now flying low so as to not be detected, the over-the-horizon RF weapon, officially called the QR-23 but nick-named "Mindbender" for its ability to cause devastating confusion in adversary systems and decision makers alike, now cruised at low altitude toward the enemy carrier strike group using its internal orientation, since some of the GPS constellation had also been lost in the EMP attack on Taiwan. The UAV came pre-loaded with the most-up-to-date intelligence on PRC emissions, and the characteristics of specific emitters for them to be identified. The Mindbender identifies the air control radar located at the highest point on the carrier in the midst of launching a J-20. The Mindbender immediately enters its scout profile, identifying and ranging the radars, correlating them to platforms and electronic systems the Mindbender could disrupt or destroy. At the speed of light, the UAV begins its attack, sending high-power microwave energy at its targets, hitting each LUYANG II with more than 40 shots a piece. The UAV made no indication of its attack, except for the carnage that could be witnessed only through a spectrum analyzer. Befuddled watchstanders on board the PLA(N) platforms flicked on and off switches, and restarted computer systems that seemed to either freeze at DOS prompts, or never return from their darkened state. What had been a well-organized, capable strike group became a gaggle of disoriented gray hulls unsure of itself and its abilities to meet the mission it had just moments before been confident it would complete. Electronics technicians and radar operators searched frantically for the resolution to return radars and equipment to functioning condition, replacing circuit

cards and battery supplies, only to have to continue to chase “the gremlin” in a never-ending troubleshooting effort. The PRC strike group was now entirely vulnerable. The predators had become sitting ducks.

Back on COWPENS, the electronic warfare specialists reported the action observed in their spectrum analyzers to the TAO, who immediately knew a Mindbender was at work over the horizon. COWPENS closed the bearing and ordered a full assault by the SAG, devastating the PRC units with surface-to-surface missiles. The tide of the battle had been reversed with victory achieved by actions taken in the invisible electromagnetic spectrum.

Introduction

Adversary militaries are increasing their reliance upon computers and electronic systems on land and at sea, presenting a potential critical vulnerability that, if exploited, could enable friendly forces to achieve tactical objectives leading to operational success. Electronic systems, such as radars, navigation, and various supervisory control and data acquisition (SCADA) systems on military installations and naval platforms have become reliant upon electronics whose components may be vulnerable to disruption and/or destruction. Modern warships rely heavily upon a dense infrastructure of electronic systems to collect and process data to enhance the adversary's decision-making capability. Additionally, seemingly innocuous electronic systems, such as an atmospheric monitoring system that regulate temperature in engineering spaces could provide an unanticipated backdoor to producing effects that could render a platform incapable of continuing on mission and achieving its mission objectives. Disrupting these systems will become crucial in times of war, when seconds of confusion in a decision-maker's process could mean the difference between mission success and failure, or life and death.

The unique characteristics of the RF spectrum has allowed for the development of a capability to project destructive energy within the information domain, causing devastating effects at the speed of light. Joint Publication 3-51 defines electronic attack (EA) as the use of electromagnetic (EM) energy, directed energy, or anti-radiation weapons to attack personnel, facilities, or equipment with the intent of degrading, neutralizing, or destroying enemy combat capability and is considered a form of fires.[2] EA includes employment of weapons that use either electromagnetic pulse or directed energy as their primary destructive

2 United States of America. Joint Chiefs of Staff. JP 3-51 *Joint Doctrine for Electronic Warfare*. Washington, D.C.: Joint Chiefs of Staff, 2000. 15.

mechanism (lasers, radiofrequency weapons, or particle beams).[3]

Since World War II, the speed and distances of war at sea have continued to advance at a break-neck speed with an increasing complexity of systems required to support it. The U.S. Navy has developed its capabilities centered on a massing of forces, such as the Carrier Strike Group (CSG) and Expeditionary Strike Group (ESG), comprised of multiple capital ships reliant upon each other to achieve collective superiority across all Naval warfare areas. For this reason, electronic attack has been relegated to a power projected from the aircraft carrier (CVN) and its EA-18G fighters primarily occupied with supporting fighter strike packages through suppression of enemy air defenses (SEAD).

Electronic attack capability currently available beside the EA-18G squadrons on surface other and subsurface platforms has been constrained to self-defense, providing only a line-of-sight jamming capability to defeat incoming air-breathing threats (ABT) such as anti-surface cruise missiles. Meanwhile other warfare areas, such as anti-air warfare (AAW), anti-surface warfare (ASUW), and Anti-Ballistic Missile Defense (ABMD) have continued to expand capabilities to keep pace with the increasing trend of speed and range of naval warfare, Electronic warfare on cruisers, destroyers, amphibious platforms, and submarines have not followed suit.

Surface and subsurface platforms need an over-the-horizon radiofrequency weapon to deploy in order to disrupt adversary decision-making and deny the adversary's mission capability by degrading or destroying critical electronic systems at extended ranges.

3 United States of America. Joint Chiefs of Staff. JP 3-51 *Joint Doctrine for Electronic Warfare*. Washington, D.C.: Joint Chiefs of Staff, 2000. 100.

Early, decisive action in the EM spectrum

Extending the range of electronic attack allows for earlier deliberate action against the adversary in the electromagnetic spectrum. The addition and distribution of an over-the-horizon electronic attack capability will provide the JFMCC and JTF commander with more options than are currently available to project power in the electromagnetic spectrum. Additionally, radiofrequency weapons are anticipated to be more cost-effective compared to traditional kinetic weapons that offer a similar level of precision. By pursuing over-the-horizon RF weapons, the JFMCC commander can have greater confidence in the ability to mount an effective attack before the adversary can establish a defense against it or conduct an effective attack of his own. Additionally, the JFMCC commander will have a more flexible and redundant electromagnetic arsenal at his disposal, which will simultaneously complicate the adversary's task of defending against it. Finally, the JFMCC commander can avoid the overall cost and loss of resources associated with traditional kinetic weapons while still achieving maximum operational success.

How RF Weapons Work

RF Weapon has four basic components: the power supply, the modulator, the amplifier, and the transmitter. The power supply provides the power needed to produce the electromagnetic pulses. Different power sources have been used in different designs, such as electrical generators, battery, or by capturing the energy caused by controlled explosions. However, explosions are generally not ideal, as the results of the explosions are not precise.[4]

Once the pulse has been generated in the power section, the pulse is conditioned, or

[4] Tatum, John. *"HPM DEWs And Their Effects on Electronic Targets."* DSIAC, Summer 2017, 4, no. 3 (June 2017): 2.

modulated. The modulator, consisting of pulse-forming networks and high-power switches, converts the pulse into the electrical pulses with specific emission characteristics such as pulse repetition frequency (PRF), pulse width, and frequency. The purpose of this step is to prepare the pulse as a form to be transmitted as a radio wave. High-power tubes, such as magnetrons, or high- power amplifiers such as klystrons are typically utilized for this section.[5]

The final internal step is the transmission of the RF signal. The antenna radiates the RF energy into space toward the target electronic system. For narrowband sources, antennas such as parabolic antennas are used. These types of antennas can handle the high-power output of the RF source and provide directional gain for the energy transmitted toward the target. Type of antenna used determines the gain and directivity of the signal, improving its ability to cause destruction.

Once transmitted, the RF signal travels at the speed of light (186,000 mph or 300,000,000 m/s) toward the target. Weather conditions, time of day, and other factors that need to be considered with conventional kinetic weapons are nearly negligible with an RF weapon. At much higher frequencies, the potential for some attenuation is possible in heavy rain and snow. While the signal itself travels at this speed, it is important to note that the effects of the attack may not be instantaneous, and may not be noticed at all if the attack results in subtle timing issues within a computer system which ultimately adversely affects the system's operability.[6] A typical cell phone tower transmits at approximately 500W, and can maintain a signal with a cell phone or other mobile device to a range of approximately 1-3 miles. In comparison, a

[5] Tatum, John. *"HPM DEWs And Their Effects on Electronic Targets."* DSIAC, Summer 2017, 4, no. 3 (June 2017): 2.
[6] Tatum, John. *"HPM DEWs And Their Effects on Electronic Targets."* DSIAC, Summer 2017, 4, no. 3 (June 2017): 3.

high-powered RF weapon transmits its electronic pulse at power of 10kW, approaching 2,000 times more powerful than the power radiated from the cell tower to a mobile device.

Once the signal has reached its target, it penetrates its target through at least one of two routes: the intended "front door", or the unintended "back door". RF could travel through intended paths such as receivers and antennas, or it could enter a system through "back doors" created by cracks, seams, cables and doors.[7] Due to the power of the signal, it can either overload the system components, or permanently disable them. Once the pulse reaches the component, the component will fail if the stress level caused is greater than the endurance it can withstand. If the component is critical to the electronic system's proper operations, the electronic system's overall operation will fail.[8] This ratio can be quantified, and reflected in mission planning and execution as probability of failure and probability of kill.

The Necessity for Early, Decisive Action In the EM Spectrum

Early, deliberate action in the electromagnetic spectrum supports the paramount necessity to strike effectively first. The necessity to project power over the horizon in the maritime domain is proportional to the dramatic increase in range and speed of battle in the 21st century. To meet this challenge, it is imperative that maritime platforms be able to send a weapon over the horizon to meet the enemy at a maximum effective range in order to disrupt, degrade, and destroy the adversary's electronic systems. By disrupting the adversary's ability to sense and understand his environment, the JFMCC commander will achieve a critical information and decision-making advantage.

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[7] Tatum, John. *"HPM DEWs And Their Effects on Electronic Targets."* DSIAC, Summer 2017, 4, no. 3 (June 2017): 7.

[8] Tatum, John. *"HPM DEWs And Their Effects on Electronic Targets."* DSIAC, Summer 2017, 4, no. 3 (June 2017): 4.

The numerous advantages of employing an over-the-horizon RF weapon are clearly evidenced by a close examination of Col John Boyd's "OODA Loop" decision-making model. To summarize the process, "the OODA Loop is a model of the human thought process that begins with the process of observing the environment. Based on this observation, a human categorizes what is being observed with their epistemology and decides on what actions are appropriate to respond to the situation. That action is taken and in so doing, the environment changes or responds in some way. That change is observed and the loop continues."[9] The advantage goes to the decision maker who can complete the decision making process successfully first with the best information about the environment. Over-the-horizon RF weapons represent the fundamentals of electronic attack and electronic warfare, as a subset of information operations, is to disrupt, corrupt, and usurp the adversary's decision-making capability while protecting the decision-making capability of friendly forces.[10]

The numerous electronic systems that facilitate the steps in the OODA loop could be susceptible to RF destruction and disruption. For example, the first step in the OODA Loop is the observation of the environment in order to collect information about the current environment. In modern warfare, observation of the environment is heavily reliant upon sophisticated electronic systems such as radars, communication, electro-optical sensors, infrared sensors, pressure sensors, and numerous monitoring devices. Once the adversary has collected the information from the environment, the next step in the OODA loop is to orient. During this process the new information is interpreted in the context of the existing knowledge about the operating area. Boyd states, "The individual combines the new information, previous experience, cultural conditions, genetic heritage, and analysis and synthesis methods

[9] Poisel, Richard. *Information Warfare and Electronic Warfare Systems*. Boston: Artech House, 2013. **29**
[10] United States of America. Joint Chiefs of Staff. JP 3-51 *Joint Doctrine for Electronic Warfare*. Washington, D.C.: Joint Chiefs of Staff, 2000. 15

to update the model."[11] Again, modern navies utilize electronic systems to analyze and synthesize data in order to orient, such as automated systems for safe navigation and bathymetric calculations. RF weapons could be highly effective in disrupting at this step in the decision making process. By corrupting the interpretation of information, the adversary will have an inaccurate understanding of the environment which will likely lead to a decision not conducive to the actual situation.

Due to the speed of war in the maritime domain, modern navies have incorporated automated decision making systems to assist the warfighter to quickly assess and decide on the best courses of action. Once the decision-maker has oriented his environment, he or she can decide on what action or actions to perform. The systems used for aiding in decision-making, just as those used for observation and orientation may be susceptible to RF weapon targeting. The final step in the OODA loop is the action intended to affect the state of the world by causing changes in the environment. Modern navies again rely on computer-based systems, which control all aspects of kinetic weapons that are controlled by electronic subsystems. By utilizing RF weapons, such weapons and systems may partially or completely fail to perform their intended actions correctly. Through this analysis of the OODA loop, it is clear that by extending the range of electronic attack, the JFMCC commander will gain the ability to complete the decision making process first and mount an effective offensive before the adversary can establish an effective defense against it.

Early, deliberate action in the electromagnetic spectrum denies the adversary the electronic systems required to achieve his objective. High power microwave radiofrequency weapons produce invisible beams of electromagnetic energy within the radiofrequency spectrum (0Hz-300GHz) that can cause effects ranging from temporary to permanent on targeted electronic

[11] Poisel, Richard. *Information Warfare and Electronic Warfare Systems*. Boston: Artech House, 2013. **29**

systems.[12] High-power microwave radiofrequency weapons provide a unique capability in disrupting, degrading, or destroying systems that include computer systems, security and industrial control systems, various forms of radars, and other systems that rely on semi-conductors, diodes, and silicon-based processing units.[13] Electromagnetic energy from an RF weapon "couples," or energizes an electronic target directly through the transmitter or receiver portion of the system (such as an antenna), or through a "back door", such as cable joints, cracks in infrastructure, seams, and external wires.[14] Currents and voltages can be introduced into target circuitry, resulting in erroneous signals, system lock-up, shutdown, loss of communication between systems, and possible physical damage.

In a 2016 testimony to the House Armed Services Committee, Maj. Gen Robert McMurry (USAF), Director of the Air Force Research laboratory remarked on the "game changing" technology directed energy weapons are likely to become. "The Directed Energy (DE) technologies AFRL is developing have the potential to provide unprecedented self-defense, air superiority, and precision strike capabilities with speed of light engagement, minimal collateral damage and a deep magazine. In the next five to ten years, it may be possible to use matured DE technologies to enhance the survivability of legacy and future aircraft and defend forward bases against aircraft and missiles."[15] The growing reliance on microelectronics and electrical subsystems technology by U.S. adversaries offers a tremendous incentive to pursue high-power microwave radiofrequency weapons to defeat enemy functions and capabilities.

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[12] Munro, Neil. *Electronic Combat and Modern Warfare: The Quick and the Dead*. Place of Publication Not Identified: Palgrave Macmillan, 2014. XX

13 Tatum, John. *"HPM DEWs And Their Effects on Electronic Targets."* DSIAC, Summer 2017, 4, no. 3 (June 2017): 4.

[14] Tatum, John. *"HPM DEWs And Their Effects on Electronic Targets."* 4.

[15] United States of America. U.S. House Of Representatives. Armed Services Committee. *Presentation To The House Armed Services Committee Subcommittee on Emerging Threats and Capabilities.* Robert D. McMurry, Lt. Gen. Washington, DC: U.S. Congress, 2016. 10.

Radiofrequency Weapons could revolutionize warfare by denying the use of advanced electronic systems that modern militaries have become reliant upon for nearly all functions of warfare. For example, RF weapons could disrupt and destroy computer-processing units onboard hi-tech cruise missiles, fire control radars, electro-optical sensors, and sensitive electronics state-of-the-art fighters and bombers—all at the speed of light. The result of an RF weapon attack can mean a severe degradation in functions and capabilities long after the original attack. In comparison to traditional jamming techniques where the effects are only present while the disrupting energy is being transmitted, the radiofrequency weapon will degrade or destroy the target. Denying the adversary's functions and capabilities defeats his mission.

Radiofrequency weapons attack the adversary's electronics similar to how some predators in nature debilitate their prey by spray venomous or noxious fluids to blind or numb a prey's vision or central nervous system, temporarily or permanently disabling an adversary's environmental sensing capability and information processing. Even low power pulse can destroy or damage the subsystem of an electronic ignition systems. High power radiofrequency weapons have the potential of detonating missile warheads, bombs, or artillery rounds, which may only require 0.000001 to 0.01 joules of radiofrequency per square centimeter to cause ignition of detonators.[16]

Extending the range of Electronic Attack capability allows for disruption and destruction on land and at sea, supporting lines of operation for other component commanders. By equipping surface and subsurface platforms with an over-the-horizon RF weapon, the JFMCC commander will be able to support electronic warfare efforts on

[16] Munro, Neil. Electronic Combat and Modern Warfare: The Quick and the Dead. Place of Publication Not Identified: Palgrave Macmillan, 2014.

land in order to support the Joint Forces Land Component Command (JFLCC) commander, or Joint Force Air Component Commander (JFACC) commander to provide electronic warfare functions. By providing flexibility in information operations, the JFMCC provides the JTF commander additional options to create desired effects through information operations. Concurrent with the office of Naval Research's efforts to explore directed energy weapons, the Army Research Laboratory is also pursuing options in employing this capability with land forces.[17] In a scenario where this capability is in high-demand, the Navy will be able to support by deploying an RF weapon from the sea to land in order to achieve the desired effect. Comparatively, an RF system installed and operated on the ship or submarine would require the platform to operate very close to land (radar line-of-sight), and potentially within range of land-based cruise missile threats. Additionally, the targeted electronic system may be beyond line of sight further in-land, placing them out of range.

By extending the range of electronic attack, the JFMCC commander can have greater confidence in the ability to mount an effective offensive before the adversary can establish an effective defense against it. As the reliance upon advanced electronics in the maritime domain increases, it will greatly benefit the JFMCC commander to have a means of disrupting these systems early and effectively. An over-the-horizon RF weapon will satisfy this critical requirement.

[17] Tatum, John. *"HPM DEWs And Their Effects on Electronic Targets."* DSIAC, Summer 2017, 4, no. 3 (June 2017): 4.

More options and more capability in the EM spectrum

Surface and subsurface platforms need an over-the-horizon radiofrequency weapon to deploy in order to disrupt adversary decision-making and deny the adversary's mission capability by disrupting or destroying critical electronic systems at extended ranges because the addition and distribution of an over-the-horizon electronic attack capability will improve the JFMCC commander's options beyond what is currently available to project power in the electromagnetic spectrum. First, the U.S. Navy has only one platform for electronic attack, whose tasking is prioritized to support strike operations. Second, surface and subsurface platforms have little or no electronic attack capability. Third, the electronic attack capability being developed for surface platforms is intended for defense, and/or deliberate line of sight engagements capability survivability. By providing the JFMCC commander with more options to create effects from the RF spectrum, the JFMCC commander will have greater flexibility and redundancy in capability, while simultaneously complicating the adversary's task at defending against them.

The U.S. Navy currently has only one platform for electronic attack, whose tasking is prioritized to support strike operations. The EA-18G Growler is a carrier based aircraft equipped with the ALQ-99and typically serves as the JFMCC commander's sole option for over-the-horizon electronic attack capability under operational control (OPCON). In addition to the ALQ-99 jammer, the EA-18G is armed with two AIM-120 AMRAAM or AGM-88 HARM missiles. The EA-18G has the primary role of suppression of enemy air defenses (SEAD) and escort jamming to protect friendly air-to-air and air-to-ground strike operations, while operating outside the threat envelope of known adversary anti-

air capability for its own safety.[18] Electronic destruction of naval-based electronic systems is not a primary mission of the EA-18G. Additionally, the EA-18G's reliance on the carrier for support limits its range and availability. The JFMCC commander's reliance on the EA-18G presents a critical vulnerability to its ability to produce effects within the electromagnetic spectrum. Enhancing surface and subsurface platforms with an over-the-horizon RF weapon will provide the JFMCC commander with additional options to project power beyond the horizon within the electromagnetic spectrum.

Another reason why the addition and distribution of an over-the-horizon electronic attack capability will improve the JFMCC commander's options is because currently surface and subsurface platforms have little or no electronic attack capability of their own. On board cruisers and destroyers, the highly capable multi-mission platforms in the U.S. Navy's surface fleet, there is very little electronic attack capability, and no capability that can be projected beyond radar line of sight (approximately 15 nautical miles). Meanwhile, the adversary is likely to commence his detect-to-engage process far beyond this range. The AN/SLQ-32, the backbone of the cruiser/destroyer's electronic warfare suite, is a passive system designed with the primary mission of detection and defense against incoming missiles. Of the five versions of the AN/SLQ-32, only one version (version five) has a jamming capability with the "Sidekick" add-on system. This system is only capable of causing disruption against incoming missile threats through jamming, and not permanent destruction, and is only capable of causing damage within radar line of sight. Subsurface platforms similarly languish in electronic attack capability. Surface

[18] "*NAVAIR EA-18G Growler.*" NAVAIR News RSS. Accessed April 22, 2018. http://www.navair.navy.mil/index.cfm?fuseaction=home.display&key=33BFA969-0482-42CF-9E1F-F80A1B32BEE9.

and subsurface platforms are ill equipped to take advantage of the vulnerabilities presented by the adversary's increasing dependence upon electronic systems.

The electronic attack capability being developed for surface platforms continue a trend of a defensive approach to maritime electronic warfare. This approach will likely never exploit the critical vulnerability presented by the adversary's reliance on advanced electronics. In 2002, the U.S. Navy announced the Surface Warfare Electronic Warfare Improvement Plan (SEWIP) to update the 1970's technology that had become obsolete due the rapid development of adversary anti-ship cruise missile technology. In 2016 there were 234 systems in six variants deployed worldwide, including allied forces and coast guard ships, SEWIP continues its block development, in 2018.[19]

Unfortunately, only one version of the four new versions of SEWIP has any electronic attack capability, which will still limited to radar line of sight like its predecessor. SEWIP Block III will provide electronic attack capability improvements that will provide a common EA capability to all surface combatants outfitted with the active variant of this AN/SLQ-32.[20] SEWIP represents only an evolutionary development, versus the revolutionary advancement needed to take advantage of the adversary's critical vulnerabilities in the electromagnetic spectrum.

In 2014, much excitement surrounded the implementation of the high-energy laser on board USS PONCE (AFSB(I)-15) and the testing it conducted with its laser weapon system (LaWS). LaWS employment on USS PONCE and USS PORTLAND (LPD-15) provides a glimpse into the future employment intentions for directed energy weapons. The systems were installed to the superstructure, and utilized as defensive line of sight systems, setting a precedence of the

[19] Petty, Dan. "*Navy.mil Surface Electronic Warfare Improvement Program*." The US Navy -- Fact File: Surface Electronic Warfare Improvement Program (SEWIP). Accessed April 22, 2018. http://www.navy.mil/navydata/fact_display.asp?cid=2100&tid=475&ct=2.
[20] Petty, Dan. "*Navy.mil Surface Electronic Warfare Improvement Program*."

defensive use of directed energy weapons.[21] In its promotion of DEW systems, the Army Research Laboratory advertise the use of directed energy weapons primarily for air defense against rockets, artillery, mortars, missiles, and unmanned air systems that can possibly be handled by kinetic energy weapons.[22] While defensive uses should clearly be pursued, this focus on defense will not satisfy the necessity to project this capability over the horizon to disrupt the adversary's capabilities and decision-making at range.

By providing the JFMCC commander with more options to create effects from the RF spectrum, the JFMCC commander will have greater flexibility and redundancy in capability, while simultaneously complicating the adversary's task at defending against them. Current capabilities are not equipped, nor are they readily available to meet this task, and the initial employment of directed energy weapons have been defensive in nature.

A cost effective alternative

Surface and subsurface platforms need an over-the-horizon radiofrequency weapon to deploy in order to disrupt adversary decision-making and deny the adversary's mission capability by degrading or destroying critical electronic systems at extended ranges because directed energy weapons are likely to be more cost-effective compared to kinetic weapons. Directed energy provides a multi-shot capacity, dramatically decreasing the cost to create a similar destructive effect using kinetic weapons available in the U.S. Navy's arsenal. Additionally, the scalability of the lethality will help mitigate the cost accrued from collateral damage concerns from a kinetic strike. Also, if

[21] Office of Naval Research. "*Navy.mil Laser Weapon System*." All Systems Go: Navy's Laser Weapon Ready for Summer Deployment. April 07, 2014. Accessed April 22, 2018. http://www.navy.mil/submit/display.asp?story_id=80172.

[22] Tatum, John. *"HPM DEWs And Their Effects on Electronic Targets,"* 4.

employed via unmanned systems, the risk to friendly personnel will be reduced. By enhancing the fleet with an over-the-horizon weapon, the JFMCC commander can avoid the overall cost and loss of resources associated with traditional kinetic weapons while still achieving maximum operational success.

One of the most attractive selling points to directed energy weapons is the relatively low cost anticipated in comparison to kinetic weapons to produce similar effects. In order to create similar destructive effects against adversary electronic systems, the JFMCC commander would likely have to expend costly armament and logistical support. In order to cause destruction of an adversary's radar with current kinetic weapons, the EA-18G would likely expend at least two AGM-88 High-Speed Anti-Radiation Missiles (HARM). Each of these missiles cost approximately $284,000 per unit, or $870,000 for the AGM-88E variant.[23] In order to deploy these weapons, at least one EA-18G with unit cost of $68 million would need to be deployed from an aircraft carrier. Also, EA-18G Growler pilots and Electronic Warfare Officers require years of training, which costs both time and money. Directed energy weapons offer a cost effective alternative. Directed energy weapons utilize a solid-state energy capacity (flux capacity generator) that allows for the generation of high-energy pulses. The RF weapon could conduct hundreds of high-energy attacks against multiple targets with no reload requirements. This capability would dramatically reduce the logistics cost associated with generating lethal effects to electronic systems.[24]

[23] "AGM 88 HARM Information." AGM-88B HARM. Accessed April 22, 2018. http://www.deagel.com/Offensive-Weapons/AGM-88B-HARM_a001155002.aspx.
[24] Tatum, John. *"HPM DEWs And Their Effects on Electronic Targets."* 4.

The scalability of the lethality will help mitigate the cost accrued from collateral damage concerns associated with kinetic attack options. Political sensitivity in military operations in the 21st century have demanded precision strike options to achieve political objectives that avoid collateral damage and civilian loss of life. While RF weapons would best be employed in conjunction with kinetic weapons and not in place of them, RF weapons would provide the most precise capability to target specific electronic systems without damage to civilians and surrounding facilities. Also, by adjusting the power output an RF weapon provides scalable effects to meet a particular objective similar to a warning shot with a crew-serve weapon.[25] This allows the commander to control the amount of damage caused by offensive action, versus a kinetic strike against an electronic system that is typically total and irreparable.

If employed via unmanned systems, the risk to friendly personnel will be reduced. Currently, over-the-horizon electronic attack requires EA-18G crew (pilot and EWO) to place themselves at risk of adversary anti-air capability. If an EA-18G crew is downed, combat search and rescue (CSAR) and other resources are then risked to rescue them, risking these resources and a potential political crisis could ensue if the crew were to be captured. Unmanned systems alleviate this risk by alleviating the necessity of utilizing manned delivery vehicles.

Some may argue against the use of an unmanned system for over-the-horizon targeting and offensive action. However, utilizing the experiences and lessons learned in employing the tomahawk land attack cruise missile (TLAM) as an example, overcoming

[25] Tatum, John. *"HPM DEWs And Their Effects on Electronic Targets."* 4.

these challenges may not be as insurmountable as they initially appear. The tomahawk missile is employed from multiple Naval surface and subsurface platforms, and has achieved significant success in U.S. military operations. By employing an over-the-horizon RF weapon, the JFMCC commander can avoid the overall cost and loss of resources and avoiding collateral damage associated with traditional kinetic weapons while still achieving maximum operational success**.**

Counter Argument: The High-Energy Laser

Many professionals looking forward to future warfighting capabilities and emerging technologies note that while RF weapons are effective at the destruction of electronic systems, the effectiveness is often unnoticed by the adversary or the deliverer. The speed of war will require immediacy with a high degree of confidence in effectiveness. Emerging technologies such as high-energy lasers, also a directed energy weapon with similar advertised benefits, would be a better alternative because they are more effective at physical destruction allow for immediate reliable battle damage assessment.

RF weapons do not present obvious physical destruction. Destruction using RF weapons will not provide the immediate indicators of battle damage for assessment that intelligence analysts are accustomed to observing with kinetic weapons. This could lead to the unnecessary expenditure of weapons, and a distrust of the RF weapon's performance. Additionally, high-energy lasers provide some of the same capabilities that RF weapons will, such as scalable effects and destruction at the speed of light.

Rebuttal

While it is true that RF weapons will not provide the familiar indicators of destruction that traditional kinetic weapons, or even high-energy weapons do, this can

be overcome by developing trust in the capability provided by RF weapons through a rigorous research and development process. As with radars in WWII and tomahawk missiles in the gulf war, the Navy has learned that in order to adapt new technology, it will be imperative to develop trust in its capability and train personnel on its capabilities and limitations. Additionally, RF weapons are designed to target information systems with an effectiveness and accuracy not likely to be possible with kinetic weapons or high-energy lasers. Therefore, RF weapons and kinetic weapons would be complimentary means of destruction. RF weapons could be used to attack all forms of electronic devices, sensors, and communication systems, but would not be used against the destruction of the facility itself. An over-the-horizon RF weapon provides a capability where the currently there are very few options. Finally, the subtle nature of the RF attack, and the difficulty for the adversary to diagnose its effects could be beneficial in causing the adversary to lose confidence in his systems, and ultimately his ability to achieve mission success.

Chinese Advancements and Employment of EM Weapons

The technology RF weapons are based on is not new. In fact, the technology has been in development for many decades. It has been revealed that the U.S. and the Soviet Union have had programs investigating the potential weaponization of the electromagnetic spectrum for more than 50 years. Following a nuclear test in 1962, the U.S. inadvertently discovered the potential use of the RF spectrum to cause destruction. In the years to follow, the U.S. reported marginal success, and less attention was given to the potential as priorities in defense spending shifted. With the advent of computer systems and advanced electronics, the interest returned. Now, the U.S. as well as it's near-peer adversaries (China, Russia) have reinvigorated their

programs, and have made dramatic strides in the development of radiofrequency weaponry capable of causing physical damage to electronics.

Near peer adversaries are known to have RF weapons in their arsenals. The Chinese have deployed Electronic Warfare weapons in the South China Sea at various outposts, and have used them against U.S. forces operating in the area.[26] Their use has not escalated above jamming, but demonstrates a clear interest and willingness to utilize electronic warfare in conjunction with other forms of warfare. China continues to challenge international norms on the use of electronic weapons, leading to a potential international situation as the result of physical destruction or loss of life caused by the jamming or destruction of critical equipment on an aircraft or other military platform.

In addition to electronic warfare weapons against aircraft, it has been speculated in military defense circles that China also pursues electromagnetic pulse weapons designed to disable U.S. carriers responding to a regional crisis in the South China Sea or Taiwan. China's military is developing electromagnetic pulse weapons that would be used to deter or disable a U.S. aircraft carrier such as USS RONALD REAGAN.[27] China's electronic warfare program and family of weapons referred to as "assassin's mace."[28] In Chinese folklore, the assassin's mace is a weapon used to completely neutralize a superior enemy with one swift blow, instead attempting to fight them via traditional means. The lead agency for Assassin's Mace, Chinese

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Lockie, Alex. *"China Has Jamming Equipment in the South China Sea - and the US May 'not Look Kindly on It'."* Business Insider. April 18, 2018. Accessed May 11, 2018. http://www.businessinsider.com/china-jamming-us-navy-jets-off-aircraft-carriers-pacific-2018-4.

[27] Gertz, Bill. "Report: China Building Electromagnetic Pulse Weapons for Use against U.S. Carriers." The Washington Times. July 21, 2011. Accessed May 11, 2018. https://www.washingtontimes.com/news/2011/jul/21/beijing-develops-radiation-weapons/.

[28] Gertz, Bill. "Report: China Building Electromagnetic Pulse Weapons for Use against U.S. Carriers." The Washington Times. July 21, 2011. Accessed May 11, 2018. https://www.washingtontimes.com/news/2011/jul/21/beijing-develops-radiation-weapons/.

electromagnetic pulse studies, and other directed energy applications is the China Academy for Engineering Physics.[29]

Within the Assassin's Mace program, China is reported to be developing low-yield EMP weapons that could be either air-dropped, or coupled to a ballistic missile such as the DF-21 medium-range ballistic missile, designed to hunt U.S. aircraft carriers and their accompanying warships. According to released reports, China has conducted tests on mice, rats, rabbits, dogs, and monkeys to determine the extent of damage to bodily organs and function, to fully understand the extent of the damage to be expected when used against U.S. platforms and personnel.[30] The tests are reported to also have other intentions, such as further studies into Electronic Protection (EP) of friendly forces against RF weapons, and possibly utilized for torture and interrogation. China would be interested in minimizing casualties both within Taiwan and in a U.S. Carrier Strike Group to minimize resentment and minimize the potential of a large retaliation against their interventions into Taiwan.

China Blinds U.S. Pilots with Lasers

China has also demonstrated its willingness to project power in the broader electronic spectrum. In May 2018,[31] China was publicly accused of using military-grade lasers to blind U.S. C-130 Hercules crewmen near Camp Lemonnier, Djibouti. The crewmen had to receive medical treatment following this altercation. While the use of lasers in warfare is not illegal, the use of lasers to cause physical damage to military personnel ("dazzling") is a violation of the Protocol

[29] Gertz, Bill. "Report: China Building Electromagnetic Pulse Weapons for Use against U.S. Carriers." The Washington Times. July 21, 2011. Accessed May 11, 2018. https://www.washingtontimes.com/news/2011/jul/21/beijing-develops-radiation-weapons/.

[30] Gertz, Bill. "Report: China Building Electromagnetic Pulse Weapons for Use against U.S. Carriers." The Washington Times. July 21, 2011. Accessed May 11, 2018. https://www.washingtontimes.com/news/2011/jul/21/beijing-develops-radiation-weapons/.

[31] Trevithick, Joseph. "US Military Says Chinese Lasers Injured Pilots Flying A C-130 Near Its Base in Djibouti." The Drive. May 03, 2018. Accessed May 11, 2018. http://www.thedrive.com/the-war-zone/20615/us-military-says-chinese-lasers-injured-pilots-flying-a-c-130-near-its-base-in-djibouti.

on Blinding Laser Weapons, an amendment to the 1980 Convention on Certain Conventional Weapons that restrains the use of lasers to specific functions that, in general, do not purposefully cause physical damage to personnel. The weapon used in this case is reportedly designed to look similar to assault rifles employed by PLA forces to obfuscate its presence and employment.[32]

Conclusion

Surface and subsurface platforms need an over-the-horizon radiofrequency weapon to deploy in order to disrupt adversary decision-making and deny the adversary's mission capability by degrading or destroying critical electronic systems at extended ranges. Extending the range of electronic attack allows for earlier deliberate action against the adversary in the electromagnetic spectrum. The addition and distribution of an over-the-horizon electronic attack capability will provide the JFMCC and JTF commander with more options than are currently available to project power in the electromagnetic spectrum. Finally, electronic attack is anticipated to be more cost-effective compared to traditional kinetic weapons that would currently be used to achieve a similar destructive outcome. By pursuing over-the-horizon RF weapons, the JFMCC commander can have greater confidence in the ability to mount an effective attack before the adversary can establish an defense against it, or conduct an effective attack of his own. Additionally, the JFMCC commander will have a more flexible and redundant electromagnetic arsenal at his disposal, which will simultaneously complicate the adversary's task of defending against it. Finally, the JFMCC commander can avoid the overall cost and loss of resources associated with traditional kinetic weapons while

[32] Trevithick, Joseph. "US Military Says Chinese Lasers Injured Pilots Flying A C-130 Near Its Base in Djibouti." The Drive. May 03, 2018. Accessed May 11, 2018. http://www.thedrive.com/the-war-zone/20615/us-military-says-chinese-lasers-injured-pilots-flying-a-c-130-near-its-base-in-djibouti.

still achieving maximum operational success.

Recommendation:

The U.S. Navy should aggressively pursue an air-breathing delivery platform capable of being launched from surface and subsurface platforms to maneuver over-the-horizon and utilize its high-power RF electromagnetic pulses to degrade or destroy targeted electronic systems in the maritime and land environments. The deployment system should be designed with the means to infiltrate enemy air radar surveillance in order to deliver its effects. Retrieval of the system is desired, but not required. Supporting Intelligence efforts should focus on the parameters required to defeat adversary electronic systems in order to meet the intelligence needed for pre-mission planning and programming of the RF weapon to target the electronic systems of units at sea and facilities on land.

In order to effectively deploy the system in a denied electromagnetic environment, surface and subsurface units deploying the RF weapon should be equipped with planning systems for electronic warfare specialists to utilize to plan missions if reach-back to supporting strike commands is not available.

Current efforts by the U.S. Air Force Laboratory in conjunction with sister services through the High Energy Joint Electromagnetic Non-Kinetic System (HIJENKS) has demonstrated great promise toward a jointly produced system as described in this recommendation.[33] The U.S. Navy should continue its support of this project for the reasons outlined in this research project.

[33] United States of America. U.S. House of Representatives. Armed Services Committee. *Presentation To The House Armed Services Committee Subcommittee on Emerging Threats and Capabilities.* Robert D. McMurry, Lt. Gen. Washington, DC: U.S. Congress, 2016. 10.

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