HIGH POWER MICROWAVE WEAPONS:

DISRUPTIVE TECHNOLOGY FOR THE FUTURE

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As the Department of Defense has shifted focus to near-peer competition, there has been a push to field technologies that will offer the United States a strategic advantage. The Air Force Research Lab (AFRL) has been designing, building, and testing technologies that can provide this advantage, but many have never made it to the operational inventory. One of those technologies is Pulsed-wave High Power Microwaves (HPM). HPMS has been in development for over 30 years and has seen significant advancements in the size, weight, and power of the weapon. These weapons started as large ground-based systems, but in 2012 the technology had advanced to the point that AFRL placed it on an airborne platform. Since this technology demonstration, AFRL has continued to pursue advancements in this technology. HPMs also provide an opportunity to revisit an old nuclear targeting strategy, countervalue strikes. HPMs can be used to strike targets that are vital to the survival of the nation while negating collateral damage concerns. These weapons provide a unique capability to deter potential adversaries from taking action or compelling them to stop a course of action. These weapons are the type of disruptive technology the US needs to maintain its competitive advantage.

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Introduction

The United States (US) has made a dedicated effort to shift focus to a conventional peer-on-peer fight, while still engaging in asymmetric conflicts around the globe. The US needs to have the capability to engage in conflicts across the range of military options. While the military has engaged in low-intensity conflict, its research laboratories, in conjunction with industry, have been pursuing technology that will ensure the US maintains its strategic advantage. In the last few years, there have been several mandates for the Department of Defense (DoD) to research and field directed energy weapons. The 2018 National Defense Authorization Act (NDAA) mandated the establishment of a program to prototype and demonstrate directed energy weapons (DEWs) that will guarantee the military superiority of the US.[1] The NDAA's mandate is driving the requirement for the military branches to find ways to transition DEWs to the operational inventory.[2]

The Air Force created a Directed Energy Flight Plan, which describes DEWs as a technology that can "precisely engage targets of interest with little to no collateral damage or detectible disturbance."[3] These weapons are being called "game-changing" because of their unique capabilities.[4] DEWs give the US Government options if or when it decides to take action in response to a countries belligerent behavior. Fielding DEWs, more specifically high-powered microwaves (HPMs), meets the intent of the 2018 NDAA and is directly in line with the National Defense Strategy's (NDS) goal of increasing joint lethality in contested environments with the use of the non-kinetic precision strike.[5] This study contends that HPMs are viable weapons that have the potential to be deployed in the operational environment in the next five to ten years. HPM weapons provide politicians and military leaders with response options across the range of military operations. HPMs are the type of disruptive technology that will be needed for the US to maintain its competitive advantage.

High Power Microwaves

There are two primary types of HPMs weapons in development: continuous- and pulsed-wave HPMs. Continuous-wave HPMs deliver a constant stream of microwave energy in a wide area used in area denial operations against personnel or small electronics, like unmanned aerial systems (UAS). [6] Pulsed-wave HPMs deliver a high power, short-duration pulses of microwave energy, and can provide precise targeting. Pulsed-wave HPM weapons engage a specific target set with the intent to destroy or degrade its electrical components.

Pulsed-wave HPMs deliver a high power, short bursts of radiofrequency at a given target set. HPMs operate within a wide range of frequencies that transmit to the target with the intent to "degrade or destroy" electrical components. These frequencies range from 1 megahertz to 100 gigahertz.[7] It will be vital to know the target frequency because it determines how much energy will penetrate the target electronics to achieve the desired effect. Energy transfer is affected by the ability of the HPMs frequency transmission to match with that of the target. This effect is called in-band or out-of-band. In-band is when the transmissions' frequency matches that of the receiver making coupling easy to achieve and destructive effects capable.[8] Out-of-band is when these two do not match, meaning coupling will be harder to achieve, and not as much energy will reach the target. The amount of energy getting to the target system is affected by the way the energy propagates through the atmosphere.

HPMs are capable of transmitting in a wide array of bands. The bands HPMs can transmit through are narrowband, wideband, and ultrawideband. Narrowband transmissions provide a higher amount of microwave energy to a target, but coupling is harder to achieve.[9] These transmissions are accurate and ensure that more microwave energy reaches the target. Ultra-wideband transmissions do not focus on a particular target; therefore, they can propagate microwaves across a larger area. Also, ultrawideband transmissions have a higher chance of coupling with the target system, but they deliver less microwave energy to the target.[10]

HPM power sources have seen a reduction in size and weight while increasing power output resulting in increases to maximum effective ranges. In 2003 a 400-pound device was capable of producing 20 gigawatts of power, and in 2016, several HPMs in development could create terawatts of energy.[11] As the pulsed power levels have increased, and the weight of these systems decreases, it is becoming more feasible to put these systems on smaller and smaller platforms. Developments have also increased the ranges from which HPMs can successfully engage a target. In 2002, HPMs had relatively short ranges, but in 2016 they began to be capable of delivering effects from hundreds of meters away.[12] In 2030, it could be as far as miles.[13] As this technology continues to mature, size and weight will continue to decrease while power output increases, there will be more platform options for the deployment of HPM weapons.

Previous HPM Platforms/Capabilities

AFRL has developed several HPM weapons through years that have incorporated the advancement in technology. In the late 1980s, the Air Force (AF) began unclassified testing of Gypsy. Gypsy was an HPM capable of producing one gigawatt of power.[14] When tested, it was successful at destroying the circuitry in a bank of personal computers.[15] Gypsy was the starting point for the AF and its pursuit of this technology. In 1997, the Joint Non-Lethal Weapons Program funded the development of the Active Denial System.[16] The Active Denial System is a "long-range non-lethal, directed energy counter-personnel capability that projects…millimeter waves at a range of 1,000 meters."[17] The Active Denial System is a pulsed-wave millimeter system designed to counter personnel. This system has gone through several iterations and deployed to Afghanistan, but returned from theater unused.[18] The Active Denial System development focused on giving forces on the ground options during escalation of force scenarios. The Active Denial System has provided a launchpad for further development of HPM technology.

The first airborne HPM, Counter-electronics High Power Microwave Missile Project (CHAMP), has paved the way for the operationalization of this revolutionary technology. CHAMP combined AFRL's research and development on HPM effects with a proven weapons delivery platform. Boeing was awarded a $38 million contract in April 2009 to "develop and test a nonlethal, high power microwave (HPM) airborne demonstrator."[19] CHAMP integrated AFRL's HPM technology produced by Ktech, Sandia Labs pulsed power source, and Boeing's AGM-86 Conventional Air-Launched Cruise Missile body (CALCM).[20] The combination of these systems creates an unmanned system capable of flying into a contested area. When CHAMP arrives on station, it can deliver a shot from the HPM weapon designed to disable an adversary's electronics system avoiding any damage to the structure.[21] In 2012, AFRL and the companies that developed CHAMP flew the first test mission.

The 2012 test demonstrated the capability of the system and determined HPM employment in the operational environment is feasible. The CHAMP team took the weapons system to the Utah test range, where several targets housing electronics were engaged. Boeing stated, "the CHAMP missile pointed at a set of simulated targets, confirming that the missile could be controlled and timed while using an HPM system against multiple targets and locations in a single mission."[22] During the test mission, CHAMP flew a preprogrammed route and engaged seven target buildings, some multi-story, in a one-hour time frame.[23] Following the tests, AFRL's Directed Energy office confirmed that the CHAMP test had achieved the desired results.[24] CHAMP was successful at shutting down computer systems as well as the cameras filming the test.[25] This capability demonstration highlighted the potential of airborne HPMs, but it also highlighted areas that needed improvement, driving the requirement for a follow-on system.

Building off of the success of CHAMP and attempting to increase the capability, AFRL, in conjunction with the Office of Naval Research, has been developing the High Power Joint Electromagnetic Non-Kinetic Strike (HIJENKS) weapon. HIJENKS will include improvements that "resolve operational issues" that the CHAMP team experienced with the first airborne HPM system.[26] These improvements will most likely involve decreases in size and weight of the HPM payload while seeing an increase in maximum power. HIJENKS will also see improvements to the delivery vehicle. CHAMP's AGM-86 delivery vehicle was initially developed in 1974 and has recently been retired from the AF inventory. AFRL states, HIJENKS is an intermediate step to getting HPMS on an AF platform.[27] There has been speculation that the HPM payload may get matched with the Joint Air-to-Surface Missile-Extended Range (JASSM-ER).[28] The JASSM-ER delivery vehicle would increase the operational range to over 1,000 miles, a 400-mile increase over CHAMP.[29] The JASSM-ER would not only increase range but its stealth capabilities making it easier to penetrate contested air spaces. Having stealthy characteristics gives the weapons system the ability to "sneak into a denied area and neutralize an opponent's key sensor networks and command and control nodes."[30] These numbers are only speculative at the moment, and until unclassified testing of the system occurs, no further information can be derived. As of right now, the operational flight demonstration will not happen until sometime in

2022.[31] These initial demonstrations suggest that HPMs have the potential to pair with smaller delivery vehicles and different aircraft components.

Deploying Future HPM Platforms

When the AF operationalizes HPM weapon systems, it will be essential to think about how and where to deploy these assets. The future of operational HPMs is developing in three significant areas. The first is an evolution of the CHAMP system. It is an airborne HPM placed on a more capable platform. Deploying these assets could look like any other cruise missile deployment. Second is placing these systems onto a low-cost platform like the XQ-58. These systems could deploy to remote locations in containers to be stored until needed. Lastly, is a pod version of an HPMs that fit on to aircraft capable of attaching external pods. These systems could be prepositioned or deployed as need. Having various HPM platforms in the future will enhance the options available to leadership should this capability be needed in a particular theater of operations.

If the AF decides to place the HPM power source onto a cruise missile like the JASSM-ER, then deployment, storage, and transportation should be like that of any other cruise missile. JASSM-ER HPMs will collocate with aircraft that can carry and launch them like the B-1, B-2, B-52, and F-15E. The long-range bombers would have to have these assets loaded before departing from their home or deployed bases. F-15Es would also have to deploy with the JASSM-ER HPM variant. Before any of these aircraft take off, the JASSM-ER would have pre-programmed flight paths and target list uploaded. Once launched from the aircraft, the JASSM-ER would fly the HPM payload on its pre-programmed route enabling it to strike loaded targets.

AFRL is currently pursuing Low-Cost Attritable Aircraft Technology (LCAAT). LCAAT technologies are an attempt to bring capable platforms into service while keeping it at a lower price point than conventional manned aircraft.[32] Kratos, as part of AFRL LCAAT program, has developed and successfully demonstrated the XQ-58 Valkyrie. The XQ-58 is a stealthy platform with a 3,000-mile range that is capable of carrying a 500-pound payload.[33] LCAATs of the future will be enabled to work in conjunction with the AF's most capable aircraft and aircraft of the future. Additionally, the Department of the Navy is looking for options to place HPMs in small electronic warfare jamming pods and retrofitting them onto rotary-wing aircraft.[34] Creating an HPM payload that can be placed within small pods and attached to rotary-wing aircraft opens the door to the possibilities of future HPM employment.

If the AF decides to place the HPMs onto an LCAAT, like the XQ-58, there maybe be options to deploy them from shipping containers. Kratos, the manufacturer of the XQ-58, has developed a self-contained launcher system for the XQ-58.[35] Kratos's model shows the XQ-58 sitting on a rail system inside of a shipping container with its wings detached. Launching the XQ-58 will require the operator to roll it out of the container into the launching position and reattaching the wings. After being reassembled, it will prepare to launch in order to conduct its mission. Also, the model appears to show additional space where fuel and other necessary equipment could be stored to enable launches from expeditionary locations. Having these systems in a non-descript shipping container would allow the AF to preposition these assets in theater long before any conflict with a near-peer. This approach fits nicely with US Indo-Pacific Command's plan to use Forward Arming and Refueling Points (FARP) in a conflict with China. FARPs use expeditionary airfields in the region to refuel and rearm aircraft after dispersing from large installations in the Indo-Pacific region.[36] Containerized XQ-58s or similar platforms outfitted with HPMs could be collocated and launched from these remote airbases. Having containerized systems like this would ensure there would be personnel on station to reassemble them in time to launch to meet time on target requirements.

If the Navy's pod variant of HPMs reaches initial operating capability, then any aircraft capable of carrying external pods could be outfitted with the system. The HPM pods could deploy with the aircraft it will be used with or prepositioned in locations they would be required. These locations could be current installations in theater or FARPs in the Indo-Pacific region. HPM pods could increase the versatility of aircraft and provide a critical force multiplier in a near-peer fight.

Each of these technologies will be able to provide effects on target systems, but they differ in how they will get the HPM weapon to the target. The JASSM-ER variant provides a long-range stand-off weapons platform that is stealthy. This system has to launch from a manned aircraft, which means high-value bomber assets would have to get the JASSM-ER into range of the target. The potential problem is that this system is non-recoverable and would require some sort of kinetic explosion to destroy the missile body and the HPM when the fuel depleted. Depending on the mission, this could be a good or a bad thing. An evolution of this concept is the XQ-58 HPM. The XQ-58 provides a semi-autonomous system that is low-cost and can incorporate into current operational concepts like the loyal wingman giving this platform great flexibility. Not only does this system not have to put a human in harm's way, but it is also recoverable. Lastly, is the Pod variant. Having the pod placed on a current aircraft puts humans in harm's way, but it also puts humans indirect control of the system. For more sensitive targets, like countervalue, this could be the preferred way of employing HPMs. These systems add to the available combat power that Commanders have at their disposal, each type presenting its unique capabilities.

HPM technology will continue to advance, creating more opportunities to place these systems on different platforms, new and old. Having more platforms and options will help to legitimize the technology for operational units. Currently, AFRL and industry partners create these systems to demonstrate their potential and feasibility of the technology. Once these systems become more readily available, more training can occur. Having access to these systems at the operational level will provide an opportunity to showcase their capability and get the required buy-in so they can deploy in future conflicts.

HPM Intelligence Support Requirements

Operationalizing HPM weapons will require significant intelligence support to ensure these systems can prosecute targets effectively. Organizations operating HPMs will need to have intelligence professionals that can identify and breakdown frequencies of enemy target radars and systems. Having accurate intelligence on the target set will drive the requirement for the type of band the HPMs transmit through. Knowing what band to transmit through is essential because HPMs are most effective when they employ high pulsed power that is in-band with the target frequency using narrowband transmissions. Having accurate intelligence on the target set will ensure that maximum power is delivered to the target electronics, providing a functional kill. Intelligence support to HPM employment will be critical for them to succeed in operational missions.

Intelligence professionals will need to identify what they know about the target set. By doing this, it helps to determine the type of band to transmit in. If the intelligence professionals know detailed information about the target, then a narrowband transmission should be used. Using narrowband transmissions ensures the maximum energy delivery to the target. If little to no information is known, then ultrawideband transmissions should be used. This method does not deliver as much energy to a target and may only degrade the electrical components. Degradation could be intentional or unintentional. If the degradation of the target was unintentional, the target would need reengagement to achieve the desired effects. Knowing what band to transmit is critical because it will determine the effects it will have on the target. Having the capability to determine intended effects on targets will help to normalize HPMs and help to add them to the vast lists of weapons that commanders have at their disposal to attack targets of interest.

HPMs as a Coercive Instrument

HPM weapons allow the US to reexamine coercion through conventional means. The use of HPMs, as mentioned earlier, can be used across the range of military operations in an attempt to change an adversary's behavior. Employing a countervalue strategy enables a coercive strategy by targeting things that are vital to an adversary nation. Having the means to strike targets like this provides a unique opportunity to look at how to use HPMs across the "coercion continuum."[37] The continuum ranges from deterrence to total war. HPMs can be employed across it to attempt to coerce adversaries to do what the US wants. Coercion is defined by AF Doctrine 3-0, "is convincing an adversary to behave differently than it other otherwise would through the threat or use of force."[38] HPMs give leaders conventional options that will affect the behavior of adversary nations.

When the US wants to affect the behavior of its adversaries, there has to be a capable and credible threat. Gerson explains that in order for the US to change an adversary' s behavior, there needs to be military capability and political willpower.[39] Military capability is established by conducting demonstrations of the weapons system and being broadcasted in open source videos. Much like the US currently does with other weapons systems. Political willpower could be more challenging to demonstrate. Problems with HPMs and political support stems from a lack of understanding of systems capabilities. The Active Denial System is a perfect example and encountered these problems. Many people in the human rights arena became severe critics of the system. Their overarching concerns stemmed from possible misuse causing short-term pain but not leaving any physical evidence as well as unknown long-term effects.[40] For other HPMs, the process of socialization needs to occur now. New technologies bring about many unknowns causing fear within the people, which ultimately affects the ability of politicians to support these systems. Without the political willpower, the credibility of these systems would not exist.

Once the credibility of these weapons becomes established in the international system, then the US can begin to use them to affect the decisions of adversary countries. The US could deploy HPMs in situations that are below the threshold of war, like Iran's 2019 attack on the Saudi oil refinery. Open-source reporting indicated that the US responded to these attacks with a cyber-attack. If HPMs were operational, they could have deployed against Iran and conducted strikes against valuable targets to the Iranian Regime. Similarly, the US could respond to North Korea's belligerent behavior, nuclear weapons tests and ballistic missile launches, with an HPM. The US could threaten to launch an HPM to deliver effects on targets of value to deter future behavior. If deterrence failed, then the US could launch these assets to strike targets to compel them to stop their behavior. Using HPMs to compel an enemy would most likely have to employ a risk strategy where the US slowly imposes costs against the adversary country.[41] The idea is that eventually, the cost will become too high, and the adversary country will change their behavior. HPMs can be used on the lower end of the ROMO to coerce the enemy, but they can coerce adversaries in high-end conflicts.

HPMs can also deliver coercive effects while engaged in operations on the opposite end conflict continuum. If the US were to go to war with a near-peer, China, or Russia, these weapons could strike countervalue targets. In this type of conflict, HPMs could use all four of Pape's strategies: punishment, risk, decapitation, and denial to coerce the enemy.[42] Punishment would come in the form of attacking the critical infrastructure of a nation to attempt to get the people to revolt against their leadership, forcing them to terminate the war. As mentioned earlier, the bombing campaign in Tokyo was a punishment campaign that did not yield the intended results. Risk would look very similar as it does in the previous paragraph, attempting to raise the cost, so the country abandons its efforts. Decapitation would be severing communication nodes in a country. Doing this would be extremely useful in hieratical nations where lower echelons cannot act without leadership direction. Destroying electrical components in command and control nodes would limit communications in the country and affect their ability to conduct operations. A denial strategy for HPMS would look at conducting strikes against targets that preventing the country from defending itself. HPMs can dismantle these targets sets in several ways, from striking strategic surface-to-air missile systems to shutting down command and control nodes. Striking these nodes would affect the ability of the country to collectively defend the nation, making it easier for other conventional assets to strike the country. All 4 of these coercive strategies are ways to change an adversary behavior making conditions more favorable for the US.

HPMs provide the US with options to affect the behavior of adversary nations across the ROMO and continuum of conflict. These weapons have to perceived as a capable threat by adversary countries, or they will not have the ability to alter their behavior. Establishing credibility will come from continued testing and demonstrations as well as achieving political support. HPMs employed using Pape's coercive airpower strategies will have the ability to deter or compel the adversary. Coercive instruments, like HPMs, can deliver effects before or during conflicts below the threshold of war or during the war itself. HPMs add to the plethora of weapons and options the US has should it need to engage in military action to coerce an enemy.

HPM Countervalue Targeting

Introducing HPMs into the operational inventory on several different platforms provides new and innovative ways of delivering non-kinetic effects on targets of value. Civilians and AF leaders will have to change how they look at problem sets. HPMs provide a unique opportunity to adjust how the US prosecutes targets. There is going to need to be a shift in thinking from "counterforce to countervalue."[43] Countervalue targeting was a strategy used by the US in the 1950s with nuclear weapons employment against the Soviet Union. The US countervalue doctrine involved targeting "the enemy's cities, destroying its civilian population and economic base."[44] Countervalue targeting with HPMs would not focus on destroying population centers or killing large amounts of civilians. It would focus on targeting the enemy's "national strength."[45] These targets could include command and control nodes, economic production, power plant control systems, and nuclear weapons facilities. These types of targets are at the center of a countries national power. Often, these targets are highly protected, but HPMs can get to these targets through both front and back doors. These doors are what link these facilities to the outside world. As conversations continue about how to employ HPMs properly, individuals need to be cautious when using countervalue terminology. Even though the concept is from nuclear weapons strategy, the effects will not be the same. The premise is to give leaders options to employ these weapons across the range of military operations. These weapon systems allow the US to prosecute targets in retaliation for belligerent behavior to striking at the heart of a nation's military and economic strength.

Transitioning to a countervalue strategy for HPM employment provides the US with options to affect the potential adversary decision mechanisms. The US can now prosecute targets that have historically been off-limits because of collateral damage concerns. This approach is very similar to what Max Smeets proposes for offensive cyber operations. He is proposing that offensive cyber operations can successfully strike countervalue targets like critical infrastructure.[46] Critical infrastructure is at the heart of a nation's power, and delivering non-kinetic effects on them could affect an enemy's decision making. Degrading or destroying a nation's critical infrastructure could raise the cost of the conflict to a point where the adversary decides the pursuit of their objectives are not worth it. HPMs would use the same targeting strategy to gain a strategic advantage. Depending on the target and number of electrical components intended to be destroyed or degraded, achieving the desired effects could be achieved with one or more shots from the HPM.

Employing HPMs toward non-military targets could cause visceral reactions from some members of the US and the AF. These reactions may stem from the historical employment of airpower in World War II, where the US firebombed Tokyo in an attempt to coerce Japan into surrendering. In this bombing campaign, the US destroyed 16 square miles around the Japanese capital and killed somewhere between 80,000 and 130,000 Japanese.[47] The US claimed that the purpose of firebombing Tokyo was to destroy military targets. What many people around the World seen as punishment through a countervalue attack on the civilian populace. HPM attacks on critical infrastructure could have unintended consequences. These second- and third-order effects must be considered before launching a countervalue strike on critical infrastructure.

Considerations like this must be made and openly discussed to ensure it does not adversely affect the will of the American people.

Furthermore, HPMs allow combatant commanders to engage some of the most challenging problems sets the US faces today, HDBTs.[48] HDBTs are locations where countries store assets that are vitally important to their security. HPMs can get after these targets because they can gain access through "airshafts, power cabling, heating, ventilation, and air conditioning (HVAC) surface ducts and access architecture."[49] Not only are HPMs capable of entering through "back doors" as described above, but they can also enter through "front doors."[50] Front door targeting occurs when the indigenous antennas and receivers of a system become the point of entry for the microwave energy that will affect the system controlling it. Having these capabilities is what provides the flexibility to the commander. It also allows the commander to take actions against another country, overtly or covertly depending on what message the US is trying to send. HPMs should not replace conventional weapons but act as a force multiplier giving commanders and politicians options to combat threats to US national security using a countervalue strategy.

Conclusion

HPM technology, while not new, is a revolutionary technology that will provide the US unique capabilities. HPMs are the type of technology that the US will need to maintain its competitive advantage of its adversaries. This technology has been in a perpetual state of evolution and has seen significant advances in capability. HPM weapons come in two types, continuous-wave and pulsed-wave, and each provides unique capabilities. This study focused on how the US could take pulsed-wave HPMs from the laboratory setting and operationalizing them to prepare for tomorrow's fight. Employing these types of weapons systems will require some changes to how intelligence professionals support the platforms to how the US conducts targeting. This study proposes that HPMs can be used to strike countervalue targets that will affect the adversaries' decision calculus. Having the ability to hold these types of targets at risk or conducting strikes against them provides the US with a new tool to coerce potential adversaries. HPM weapon systems should not replace any weapon or electronic warfare system. These systems provide alternative options when and if the US decides it needs to use the military instrument of power.

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