



INTRODUCTION TO ELECTROMAGNETIC SPECTRUM OPERATIONS

Last Updated: 30 July 2019

The Air Force operates throughout the [range of military operations](#) (ROMO) in the warfighting domains of air, space, and cyberspace. Control of air, space, and cyberspace provides the joint force with freedom of action while reducing vulnerability to enemy attacks from those domains. The [electromagnetic spectrum](#) (EMS) transcends all physical domains, and in order for the joint force to gain and maintain control in all domains, a degree of superiority in the EMS is required to conduct operations against peer- and near-peer adversaries in contested environments. Modern warfare is highly dependent on the EMS and maintaining an advantage within this discipline is necessary to enable [joint force commanders](#) (JFCs) to gain tactical, operational, and strategic advantage. Our platforms, weapon systems, and kill chains rely on the EMS – a reliance increasingly challenged by competitors and adversaries. For this reason, a comprehensive understanding of the EMS and operations within it is critical to gaining and maintaining the desired degree of control in the EMS.

INTRODUCTION

The EMS is a physical domain that exists regardless of human interaction and has physical and temporal properties, similar to the warfighting domains, which we interact with and influence. EMS-enabled capabilities are essential elements of military operations—critical enablers of multi-domain synergy. The EMS is organized by frequency and defines the types and categories of electromagnetic (EM) energy existing within the universe. The EMS is the range of frequencies of EM radiation from zero to infinity. It consists of oscillating electric and magnetic fields characterized by frequency and wavelength. The EMS is usually subdivided into frequency bands (typically 26 alphabetically designated bands) based on certain physical characteristics, including radio waves, microwaves, millimeter waves, infrared (IR) radiation, visible light, ultraviolet radiation, x-rays, and gamma rays. This includes all EM radiation, manmade and naturally occurring, that exists from below the earth's surface (e.g., extremely low frequency radio to communicate with submarines) continuing deep into space (e.g., X-band communications with deep space probes), that can affect the movement, maneuver, employment and operation of joint forces.

Electromagnetic spectrum operations (EMSO) comprise all coordinated military

actions to exploit, attack, protect, and manage the electromagnetic environment (EME) to achieve the commander's objectives. Electromagnetic warfare (EW) is a type of fires as well as an enabling capability. **Within EMSO reside the specialties of electromagnetic warfare (EW) and electromagnetic spectrum management (ESM).** EMSO refers to all actions taken in the EMS or involving the EMS regardless of their nature or adversary involvement. EW refers to military action in which forces use radiant and directed EM energy to obtain and maintain situational mastery of the EMS, by protecting spectrum-dependent systems, networks and operations; tactically sensing the [operational environment](#) (OE); and attacking where necessary, at a time and place of their choice.

Note on the Terms “Electronic” vs. “Electromagnetic”

Air Force language has evolved from using the term “electronic warfare” (and related terms such as “electronic attack,” “electronic protection,” etc.) to refer now to “electromagnetic warfare.” The legacy term, “electronic,” speaks to actions to attack and protect the electronic circuits associated with radios and radars. With expanded use of the electromagnetic spectrum (e.g., infrared applications, lasers, microwave and satellite communications, computers) the broader term “electromagnetic” is more technically accurate. This evolution also anticipates a similar change in joint doctrine.

To compete and win against peer and near-peer adversaries in modern conflict, the joint force should place a high priority on achieving control of the EMS in order to ensure freedom of action in all other domains. The EMS transcends all physical domains and the information environment simultaneously, and the lack of EMS superiority may allow adversaries to deny our access, degrade the capabilities of our EMS-dependent systems, and use the EMS to disrupt our operations. Airmen should know what portions of the EMS in which they are operating and understand how their use of the spectrum affects friendly as well as adversary systems. It is also vital that Airman recognize how Air Force EMSO fits into the larger picture of joint electromagnetic spectrum operations (JEMSO) to leverage joint capabilities and understand how to integrate and deconflict EMS activities.

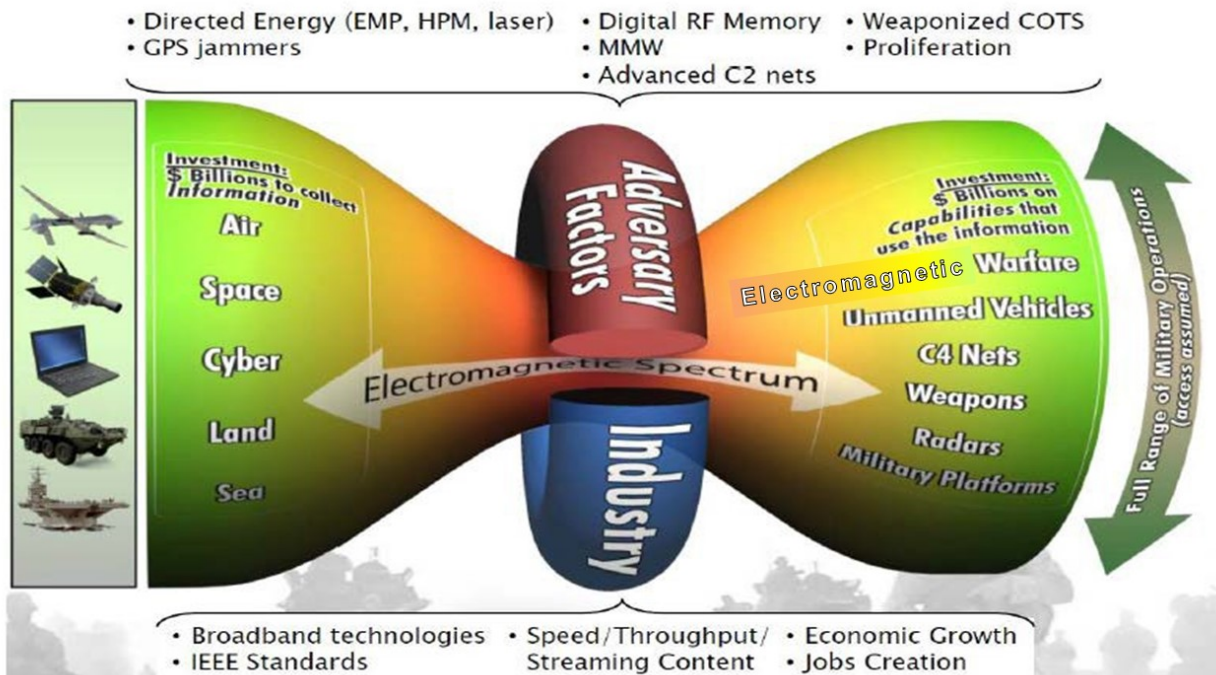
Peer and near-peer competitors have advanced EMS capabilities that they are continuously improving and integrating capabilities in all domains, which present growing challenges to the joint force's ability to achieve objectives. The Air Force brings specific capabilities to the joint force to enable the degree of control in the EMS that facilitates control of other domains. Clearly defined domains help identify the conditions and capabilities under which systems and personnel conduct operations, but do not mandate or imply command relationships.

Devices whose functions depend upon the EMS are used by both civilian and military organizations and individuals for intelligence, surveillance, and reconnaissance (ISR); communications; positioning, navigation, and timing (PNT); sensing; [command and](#)

[control](#) (C2); attack; ranging; data transmission; and information storage and processing. Warfighting in the EMS is not new. Competing powers have witnessed America's dominance on the battlefield and perceive our reliance on the spectrum as a vulnerability. These competing powers have organized, trained, and equipped forces to engage and maneuver within the EMS, in order to gain military advantage. Some have invested heavily to counter America's radar, navigation, communication, and data link advantages. In some instances, the US has not kept pace, and our technological advantages are eroding. The joint force may not be able to operate effectively if it allows adversaries to achieve EMS superiority at times and places of their choosing.

However, the Department of Defense (DOD) also cannot afford to defend or harden every node and position, nor can it address all capability gaps by simply countering adversaries' moves. The DOD must generate overmatching EMS sensing, maneuver, and engagement capabilities that collectively present an impasse for any potential adversary. Ultimately, the US must contest, then gain and maintain, superiority in the EMS.

The joint force is dependent on the freedom of maneuver in the EMS across the ROMO. To prevail in future conflicts, the Air Force should support the joint force's efforts to win the fight for EMS control. It requires significant integration between the spectrum management community, Service components, combatant commands, and allies. Achieving this superiority is complicated by increasing civilian and military EMS use, [electromagnetic operational environment](#) (EMOE) congestion, and the growth of EMS threats (See figure, "Control Challenges in an EMS Contested or Congested Environment").



Control Challenges in an EMS Contested or Congested Environment

The DOD requires an overmatching, offensive approach to EW that will place our

potential adversaries in a dilemma: they will either have to invest heavily to defend their growing reliance on the EMS, or invest heavily to achieve offensive capability parity with the US. Airmen should develop EMS awareness, engagement, and maneuver capabilities that span and connect all other domains and enable operations (e.g., suppression of enemy air defenses, counterspace, ballistic and long-range missile defense), and within the shared space between the EMS and cyberspace. This will allow them to render adversary sensors, networks, and decision processes ineffective, preventing adversaries from responding effectively in real time. The Air Force supports the joint force's endeavors to exploit broad portions of the EMS, automatically manage waveforms and power levels as necessary, and employ adaptive technology to negate adversary capabilities. Global dependence on the EMS offers the joint force increasing opportunities to exploit new attack vectors through all phases of conflict. Dominant EW expertise and capabilities can negate adversary situational awareness and command and control, and develop kill-chain targeting solutions affecting enemy operations in all domains.

Spectrum-dependent commercial and military systems have become ubiquitous since World War II. This dependence will necessitate that future combatants contend for EMS superiority in every phase of conflict. The three divisions of EW, [electromagnetic protection](#)¹ (EP), [electromagnetic warfare support](#)² (ES), and [electromagnetic attack](#)³ (EA), form the capabilities with which the joint force gains EMS superiority. EMS superiority is the degree of advantage in the EMS that permits the conduct of operations at a given time and place without prohibitive interference, while affecting the adversary's ability to do the same. EW has had strategic consequences in every conflict from World War II through current operations.

Modern conflict may often depend on achieving competitive advantage within a contested EMS environment. *Competitive advantage* in battle is rooted on foundational actions— developed and maintained institutional expertise, advanced technical training, and actively preserved core competency relevance. Our peer and near-peer adversaries organize, invest, and train to challenge and control the EMS as a dedicated military profession.

Overview of Electromagnetic Spectrum Operations

The EMS is the range of all frequencies of EM radiation and consists of oscillating electric and magnetic fields characterized by frequency and wavelength (see figure, "The Electromagnetic Spectrum").

The EMS is:

★ **Physical.** It is part of the physical environment characterized by frequency, energy,

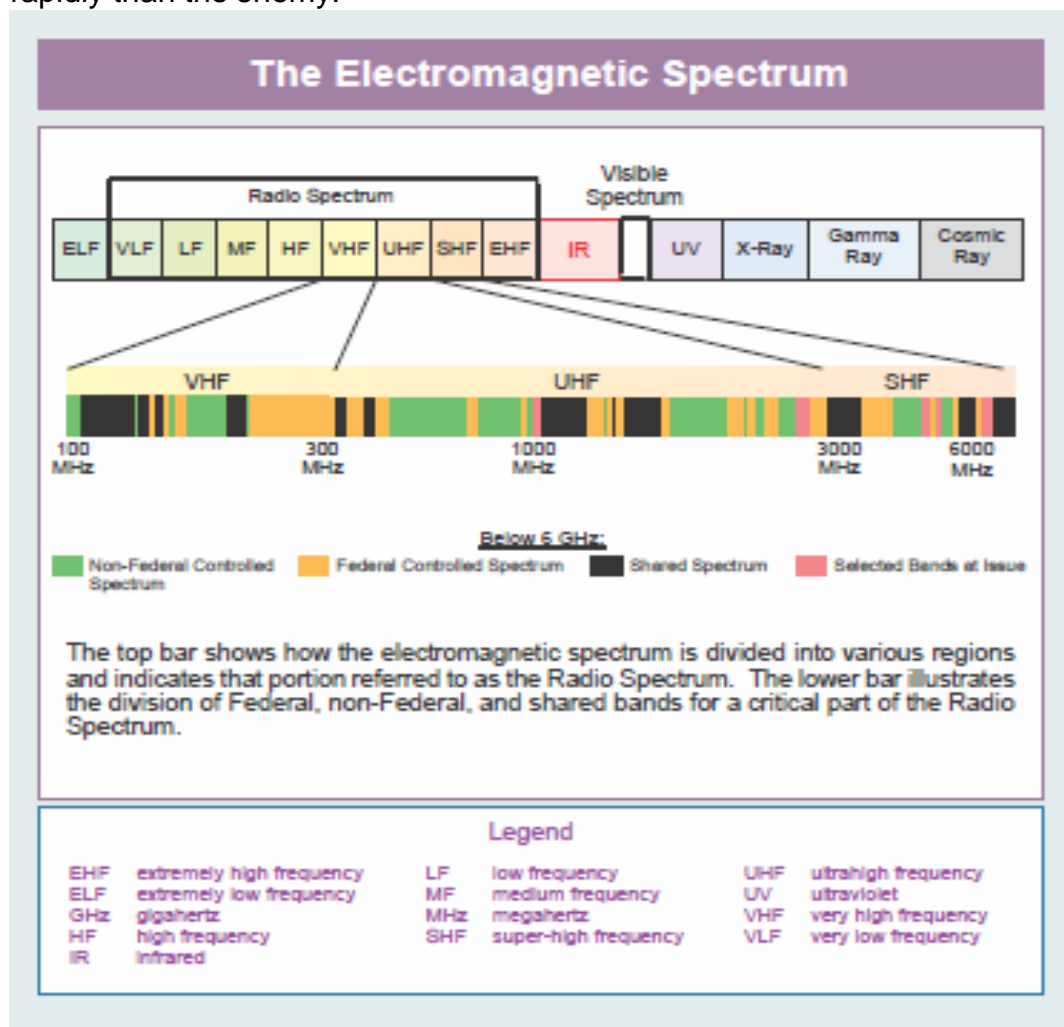
¹ For the reason these terms have been changed from "electronic" to "electromagnetic," see "Note on the Terms 'Electronic' vs. 'Electromagnetic'" in this section of the annex.

² Ibid.

³ Ibid.

and time. It can be managed, occupied, and selectively controlled like the air, land, maritime, space physical domains, and cyberspace. Natural and man-made factors affect actions in and through the EMS just as in the air, on land, at sea, in space, and in cyberspace.

- ★ **Pervasive.** The EMS is pervasive and permeating, linking all domains. The wide range of effects that can be created through EMS operations makes it a potent force multiplier.
- ★ **Constrained.** Physics, policy, and technology frame the use of the EMS. Each type of EM radiation has unique physical properties that dictate its use (e.g., short- or long- range communications, sensing). Use of the EMS is subject to international law, as well as domestic law and policy. Technology bounds those portions of the EMS that are accessible and exploitable.
- ★ **Dynamic.** The potential speed of EMSO may provide a decisive advantage by enabling commanders to make decisions, conduct operations, and create effects more rapidly than the enemy.



The Electromagnetic Spectrum

Air Force Operations and the Electromagnetic Spectrum

The Air Force is critically dependent on the EMS across all functions and domains. To prevail in the next conflict against a peer- or near-peer adversary in a contested environment, the joint force must win the fight for EMS superiority. Achieving the desired level of control is complicated by increasing joint EMS-use requirements, EMS congestion, and growth of EMS threats. The Air Force, as part of the overall joint force, conducts its part of integrated JEMSO in order to achieve unity of effort, resulting in the required degree of EMS control.

For further information on EMS superiority, see the *National Military Strategic Plan for Electronic Warfare*, and the [Joint Concept for Electromagnetic Spectrum Operations](#).

Rapid advances in EMS technologies have led to an exponential increase in commercial and military EMS-enabled and dependent capabilities. This proliferation, coupled with the US military's heavy reliance on the EMS and the low entry costs for adversaries, poses significant military challenges to the [commander, Air Force forces](#) (COMAFFOR), who is usually also the [joint force air component commander](#) (JFACC), or the joint force space component commander, and ultimately for the JFC. Integrated EMSO are required to achieve the desired degree of EMS control, which may be an essential or even decisive aspect of all joint operations.

EMSO are versatile in that they are capable of achieving effects in their own right and enabling effects within other domains. An example of a direct EMS effect is the offensive jamming of an enemy radar system, denying that system the use of the EMS. An enabled effect might be the delivery of an information operations message via radio broadcast. This is an enabled effect rather than a direct one in that the message is not inherently tied to the EMS and could be delivered via other means, such as airdrop or human-delivered pamphlets, where the jamming effects are, by necessity, conducted within the EMS.

The scope of EMSO is global and extends from below the earth's surface into space. Unfettered access to selected portions of the EMS is critical for weapon system effectiveness and protection of critical assets. It is important to realize that EMSO includes not simply radio and radar emanations, but all EM energy propagating through free space as well as EM signals transmitted through contained mediums such as wiring or optical fiber. As such, operations within the EMS can be hindered by adversary action, environmental factors, or conflict with friendly EMS systems. These factors should be taken into account when planning to operate in the EMS, so that proper mitigation, deconfliction, integration, and countermeasures are in place to ensure continued operations.

The Electromagnetic Environment (EME) is, "the resulting product of the power and time distribution, in various frequency ranges, of the radiated or conducted EM emission levels encountered by a military force, system, or platform when performing its assigned mission in its intended OE" (Joint Publication [JP] 3-13.1, [Electronic Warfare](#)). Not all

EM radiation encountered by forces will impact operations. Friendly forces should prepare to operate in highly contested and non-permissive EME and understand EMSO's potential to increase force effectiveness. Intentional and unintentional emissions from military forces as well as the natural environment, may aggravate the EME's contested nature. EM interference and hazards to personnel, ordnance, and volatile materials may be caused by [electromagnetic pulse](#) (EMP), as well as natural phenomena, such as the effects of sunspots, lightning, and precipitation static. For example, clouds, sun glint, ground reflections, moisture, and dust can degrade performance of systems operating in the IR and optical frequencies. Atmospheric conditions can distort radar signals causing track errors, extending the detection ranges or creating "holes" in radar coverage. Rain and frozen precipitation also affects microwave transmissions by attenuating and scattering the signal. Even disturbances on the sun and in the upper atmosphere can create radio frequency interference in radars and satellite links, impact high-frequency radio and satellite communications, and degrade Global Positioning System accuracy. Planners using forecasts of terrestrial and space environmental conditions can exploit or mitigate these effects to their advantage over an adversary.

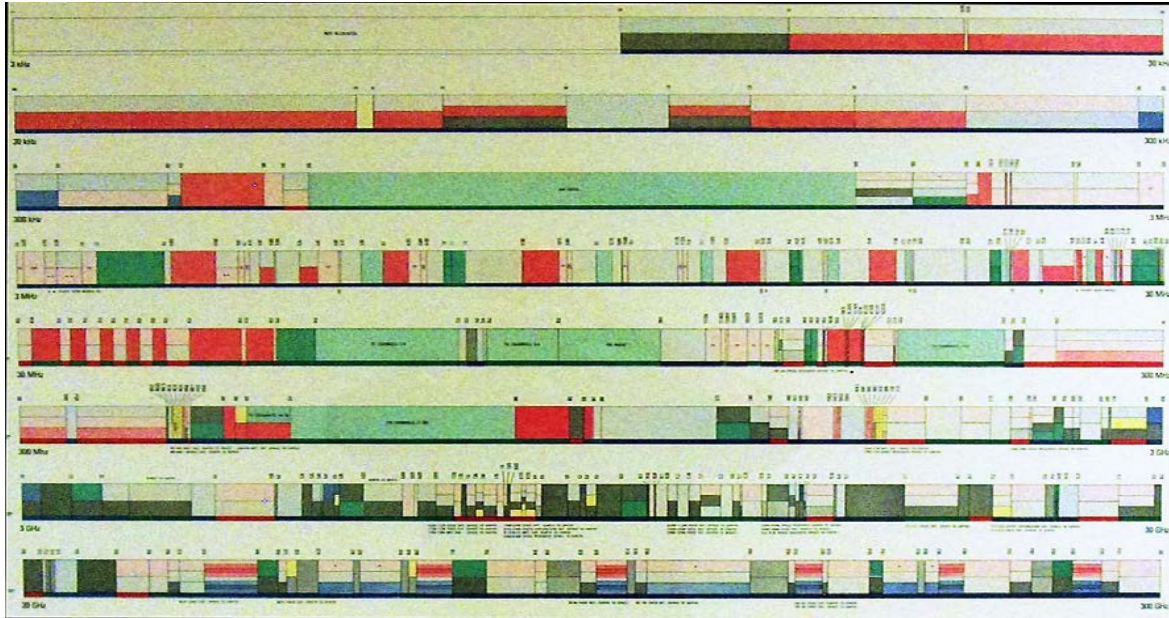
The Electromagnetic Operational Environment is the background EM radiation and the friendly, neutral, and adversarial electromagnetic⁴ order of battle (EOB) within the EM area of influence associated with a given operational area (JP 6-01, [Joint Electromagnetic Spectrum Management Operations](#)). The EMOE is a complex composite of the EM conditions, circumstances, and influences that affect the employment of capabilities and the decisions of the commander. This includes systems which are currently radiating as well as those that may radiate (i.e., systems on the EOB that have not been observed radiating).

✦ **Electromagnetic Environmental Effects (E3).** "The impact of an EMOE upon the operational capability of military forces, equipment, systems, and platforms is referred to as E3" ([JP 3-13.1](#)). All systems that operate in the EMS are susceptible to E3. The EME experienced by the Air Force are continuously changing as existing systems are modified, new systems are installed, units change proximity, adversaries transmit, or natural phenomena occur. When platforms, associated systems, and equipment (e.g., avionics, ordnance, fuel) are exposed to an EME different from those for which they were designed and tested, the potential for safety, interoperability, and reliability problems increases. Planning for E3 is critical to address E3 issues such as hazards of EM radiation in operations. These include EM compatibility, EM vulnerability, EM interference (EMI), EMP, hazards of EM radiation to personnel, hazards of EM radiation to ordnance, hazards of EM radiation to fuels, and natural phenomena effects such as lightning and precipitation static. EMSO planners review joint EMS-dependent systems for EM vulnerability, compatibility, and interoperability to identify/quantify the potential impact of E3. Critical system failure during execution can result from failing to account for E3 in planning and mitigating

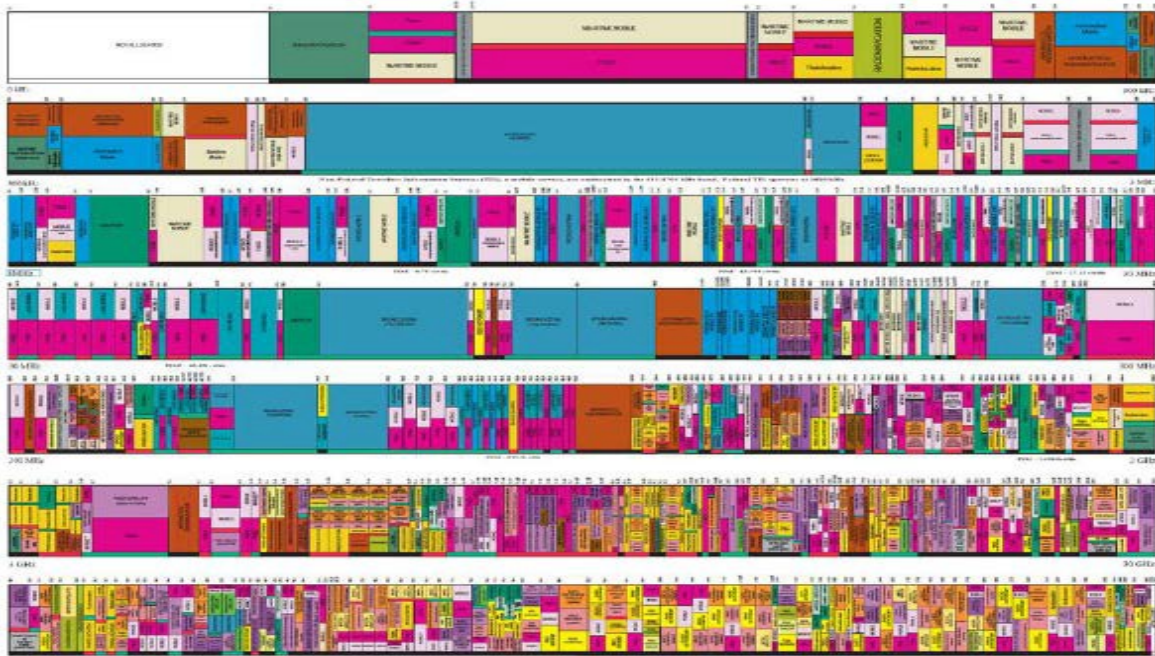
⁴ This definition is identical to existing joint doctrine except in the use of "electromagnetic" instead of "electronic." The reason for this change can be found in the "Note on the Terms 'Electronic' vs. 'Electromagnetic'" in this section of the annex.

potential EMI. For further information on E3, see [JP 3-13.1](#), and [JP6-01](#).

- ✦ **EMS Congestion.** The EMS typically encountered today is congested due to the increasing density of EM emitters. Myriad interests (such as cell phone and wireless internet providers) continue to expand their EMS footprint, reducing the open EM areas conducive to Air Force use and maneuver within the EMS. Other civil uses and other government entities consume large portions of the spectrum outside of DOD.



The Electromagnetic Spectrum, circa 1970



The Electromagnetic Spectrum, circa 2016

- ★ **The Electromagnetic Threat.** Worldwide, tens of thousands of EMS-dependent weapons systems exist and are constantly being proliferated and enhanced. Current EMS threats include systems that can detect, exploit, deny, disrupt, and deceive virtually all multinational operational capabilities, including navigation, communications, and sensors. Destructive EM weapons that directly attack personnel, sensors, platforms, C2, and infrastructure have been fielded or are under development. Concurrently, adversaries seek access to secure communications and use navigational and sensing systems to facilitate their attacks. Adversaries also have access to off-the-shelf systems, and are prepared to use them, potentially without regard to legal constraints. All of these threats to freedom of action in the EMS should be accounted and planned for in order to support and achieve the JFC's objectives. The worldwide proliferation of weapon systems, designed to counter US and multinational EMS-dependent capabilities (e.g., weapon seekers, navigation, communications), impact joint functions and overall mission success. Additionally, the operational viability of low cost directed energy (DE) weapon systems is growing, further complicating risk assessments and mission success by holding personnel, platforms, and infrastructure at risk. Enemy use of commercial off-the-shelf systems to hide among civilians increases the targeting difficulty of US and multinational planners.

Electromagnetic Spectrum Operations (EMSO) are military actions undertaken to exploit, attack, protect, and manage the EMOE. These actions include all joint force transmissions and receptions of EM energy. EMSO provides the guidance and processes to prioritize, integrate, synchronize, and deconflict all EMS actions across the joint force, enabling unity of effort. The COMAFFOR designates an electromagnetic spectrum control authority (EMSCA) and exercises unity of command for Air Force forces in the EMS through a [Non-kinetic Operations Coordination Cell \(NKOCC\)](#), facilitated by [electromagnetic battle management](#) (EMBM) to integrate and synchronize Air Force EMS use and to allow decentralized execution of EMS activity. The EMSCA provides centralized direction through the EMS control plan (EMSCP). EMSO is employed in both an offensive and defensive manner in support of the commander's objectives.

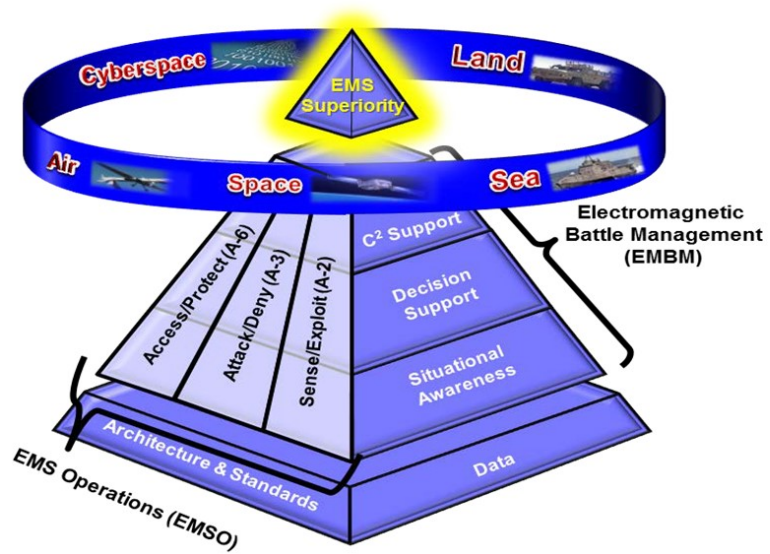
- ★ **Offensive EMSO** are intended to project power by the application of force in and through the EMS. Offensive EMSO are authorized via an EMS control order (EMSCO). Offensive EMSO are planned, prioritized, integrated, synchronized, and deconflicted along with all other forms of offensive operations in all other domains. The intent of offensive EMSO is to disrupt deny, deceive, degrade or destroy the adversary's ability to use the EMS.
- ★ **Defensive EMSO** are employed in and through the EMS to either protect joint forces from physical attack or defend friendly EMS capabilities from enemy EA. Defensive EMSO respond to unauthorized activity or alerts or threat information and leverage law enforcement, intelligence, counterintelligence, and other military capabilities as required. Defensive EMSO is accomplished using a layered, adaptive, defense-in-depth approach, incorporating emission control and mutually supporting elements of digital and physical protection.

Joint doctrine provides collective terms encompassing the EW operations described above with spectrum management. These terms are joint electromagnetic spectrum operations and [joint electromagnetic spectrum management operations](#) (JEMSMO). For more information on these terms, see [JP 3-13.1](#) and [JP 6-01](#).

Electromagnetic Battle Management and Control in the EMS

To control is to dominate the EMS, directly or indirectly, so that friendly forces may exploit or attack the adversary and protect themselves from exploitation or attack. Control is accomplished through applications of EA, ES, and EP. EA limits adversary use of the EMS; EP secures use of the EMS for friendly forces; and ES enables commanders' ability to identify and monitor actions in the EMS throughout the OE.

- ★ EMBM is the methodology used to ensure effective control of the EMOE. While control of the EMS through the proper application of EW is advantageous, improperly using EW without coordination with other entities that require use of the EMS may result in EM interference or EM fratricide. Consequently, these results might lead to unintended effects like disruption of friendly cyberspace and information networks. Additionally, an ill-timed jamming package may highlight an otherwise unseen force or deny the use of a frequency by friendly forces. An incorrect or wrongly interpreted radar warning receiver indication may cause friendly forces to react unnecessarily. EMBM is the dynamic monitoring, assessing, planning, and directing of EMSO in support of the commander's scheme of maneuver. EMBM proactively harnesses multiple platforms and diverse capabilities into a networked and cohesive sensor-decision-target-engagement system, as well as protect friendly use of the EMS, while strategically denying benefits to the adversary. The goal is a balance among the needs of the intelligence, operations, and communications communities to prioritize, deconflict, and ultimately maximize the advantage of our capabilities in the EMS to dominate through EMSO.



KEY:
 C2 – Command and control
 EMS – Electromagnetic spectrum

Concept for EMBM in relation to EMSO
