SUPREMACY IN THE ELECTROMAGNETIC SPECTRUM

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Supremacy in the electromagnetic spectrum provides additional options and increased flexibility in any competition, even other than military conflicts, in addition to greater control of the scale of escalation. It gives policy makers and military leaders the decision space to manage events in real time while denying equivalent decision space to adversaries. At the same time, supremacy in the electromagnetic spectrum requires the collection, analysis and validation of robust information in the following key areas: electromagnetic spectrum sensors, communications, data links, radars, jamming, directed energy and infrared systems, engineering data describing the performance, characteristics and signature information of associated equipment, weapons and platforms, combat support data and modelling and simulation support. The authors describe these topics through a detailed analysis of the importance and role of supremacy in the electromagnetic spectrum.

Keywords: electromagnetic spectrum; electromagnetic environment; electronic supremacy; electronic surprise; electronic warfare;

INTRODUCTION

The study of the importance of supremacy in the *Electromagnetic Spectrum (EMS)* in modern military actions constitutes an essential component of contemporary military science and art. That is why, in all modern armed forces, achieving supremacy in the electromagnetic spectrum is consistently pursued in all phases of military conflicts, during crises and even in peace time.

It can be stated that the electromagnetic spectrum transcends geopolitical boundaries, which makes its use and availability necessary in the exercise of governance and security, in the conduct of commerce and other social activities. Therefore, electromagnetic spectrum specialists must provide national authorities with flexible and safe options regarding its use. Nations must possess EMS superiority to ensure freedom of action in all areas and to prohibit or limit the same to their adversaries. There must be a deliberate integration of traditional electronic warfare, cyber and spectrum management activities across all domains and operational environments. *"Electronic warfare is carried out in the operational electromagnetic field to ensure the freedom of action of our own forces and allied ones, in all fields while denying it to adversaries"* (David, 2021).

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As a consequence of the discoveries in physics and electronics, the development and improvement of conventional combat equipment follow the path of increasing the power of destruction, the flexibility in action and the fire rate, the distances, speed and accuracy of hits, as well as of improving the conditions for operating, maintenance and repairs.

The leap from automatization to the cyberinteraction of some elements of combat equipment and then to the achievement of weapon systems was determined by the evolution of electronics and cybernetics. The next stage is the integration of automated command and control systems and weapon systems into flexible cyber systems, adaptable to the change and the pace of combat actions.

Due to the performances achieved in the fields of microelectronics, optoelectronics and laser technology, the most spectacular evolution has been the fire control systems. Modern fire control systems, working in different regimes (automatic, semi-automatic, manual, mixed or emergency), are able to ensure the determination and calculation of target parameters, own parameters, ballistic corrections due to the ammunition used and shooting conditions, so as to ensure the maximum probability of discovering and hitting the target.

Nowadays, target detection, and especially their detection and identification, is entirely dependent on crews, aided by electro-optical sensors and other specially designed devices. This activity is made more difficult by the increasing use of camouflage, false targets, and often the sheer volume of information that must be analysed in the very short time available to open fire. It thus becomes increasingly necessary to extract targets from a complex and heavily cluttered environment with greater certainty and much faster than in previous years.

The use of electronics and informatics in modern warships has led to enhanced manoeuvrability, increased safety of close defence, automated driving in combat, and increased firepower, accuracy and speed of firing data calculations.

THE IMPORTANCE OF USING THE ELECTROMAGNETIC SPECTRUM

Currently, there is rather little emphasis on ground-based aviation routing through manual processing of radar data rather than on classic aviation routing to targets using uncoded links. The focus on equipping aircraft with autonomous or integrated navigation systems, in automated command and control systems, with airborne command points, with automated data collection, processing and display systems, as well as with modern weapon systems has led to outstanding successes of aerial actions.

The use of electronics and informatics in modern warships has led to enhanced manoeuvrability, increased safety of close defence, automated driving in combat, and increased firepower, accuracy and speed of firing data calculations. Completed with specific means of research and data interpretation, numerical navigation and ship management equipment, their interconnection in command, control, information and electronic countermeasures systems will ensure increased effectiveness in naval operations.

In the current conditions of the battlefield, the main problem is to maintain an intense pace of military actions. In order to satisfy this primordial condition, it is necessary to ensure, firstly, the continuity of the leadership of the troops, and secondly, the temporal correlation between the pace of combat actions and the time available for their preparation.

We can consider that achieving management continuity is mainly an information assurance issue. Therefore, a special emphasis is placed on the implementation and effective use of the ISR components, as follows:

- *the design of integrated systems for data collection and processing and real-time reporting to decision-making structures;*
- *the complexity of the information obtained, its veracity and timeliness by accumulating the data collected by the entire range of sensors;*
- *interconnection of fire control systems.*

Military IT systems ensure the collection, conversion, transmission, memorisation, and processing of data, as well as the distribution of the results to the beneficiaries, achieving, at all management levels, a representation that enables a quick, correct and as complete as possible awareness of tactical situations, so that the decision-making structures can issue an immediate and effective response regarding the timely engagement in action of available forces and means. The functioning of information systems entails the data exchange in a volume and at a speed corresponding to the possibilities of the means of automatic data processing and of those of communications connected in the information system.

The electronic components incorporated in the elements of military assets allow their use with high efficiency, becoming indispensable in adversary target detection, both day and night, ensuring their hitting with great precision. New categories of ammunitions resulted from the integration of modern types of sensors in computerized equipment, micro-communications, lasers and infrared radiation, which led to obtaining self-guidance systems for missiles, bombs, torpedoes etc., with great precision in hitting targets.

ROMANIAN MILITARY THINKING

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In today's conditions, the prospect of armed conflicts, knowledge and mastery of the use of the electromagnetic spectrum in crisis and war situations has become a particularly important factor in achieving success. Within the military conflicts, there was a deep and spectacular shift of effort towards the informational side, and the struggle for supremacy in the use of the electromagnetic spectrum, as a medium and support for the acquisition, transmission and efficient use of information, was accelerated.

Under these circumstances, electronic warfare has become a basic component of modern military actions. It forms an important part of military strategy, focusing on researching and neutralizing the adversary's basic electronic elements.

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"Electronic warfare, in a very general context, must be perceived as a continuous interaction between one's own and the adversary's electronic means and systems. In this regard, military history has proven that the discovery and use in combat of a new electronic system has always led the adversary to initiate scientific research in the field for the development of an electronic counter-action system, thus engaging the parties to the conflict in a continuous (and sometimes beneficial) process for the improvement of combat assets" (Boaru, David, 2022, p. 18).

THE CONCEPT OF ELECTROMAGNETIC SUPREMACY – ITS ROLE AND IMPORTANCE

Modern military actions take place in the physical space determined by the three classical dimensions, in six environments (land, naval, air, space, cyber and electromagnetic). This duality of electromagnetic processes and phenomena (viewed as environment and space), complemented by the extent of the technological advancement, determines the assessment that a fourth dimension of actions would take shape.

Between the kinetic actions, which take place in the three dimensions of physical space, certain relationships are established, some of which are of great importance for the subject addressed. Thus, the extraordinary strength that aviation has acquired since the Second World War means that, in modern warfare, operations of a certain level, both land and naval, cannot be carried out without

security and protection against this category of forces. This rule is so decisive that it has led to the abandonment of the historical terms *"land war or battle"*, *"air battle"*, respectively *"naval war or battle"* in favour of the terms *"air-land"* and *"aero-naval"* battle. Thus arose the concept of *air superiority*, meaning the need to conquer and dominate the third dimension of physical space before conquering and dominating the other two dimensions.

The kinetic actions that take place in the physical space, the generic nature of the threat, history as a fundamental factor of the current configuration, and the need to sequentially conquer and dominate its three dimensions to ensure total victory over the adversary configure the current physical space of tactical and operational actions of military confrontation. Obtaining and subsequently maintaining supremacy (superiority), in the previously stated environments, entails ensuring a continuous, active and integrated nature of all actions.

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The nuance of *"superiority"* through the use of the superlative term *"supremacy"* makes it possible to gradually express the difference between the parties in conflict, from the level of calculable and comparable force ratios (in the case of *"superiority"*) to that of expressing the obvious value gap (in the case of *"supremacy"*). It follows that the struggle for *"superiority"* may be fought by quantitatively and/or value-comparable adversaries, while the struggle for *"supremacy"* is certainly the prerogative of military powers.

The decisive influence of equipment on the transformation of the physical space of combat actions has already been well known. The application of a wide range of electronic techniques and technologies to today's war scenario has reached such widespread extent and importance that it has led to the emergence of the name *electromagnetic space* and its integration into military confrontation environments. This, as a particular form of manifestation of matter (wave and corpuscle), related to physical space dimensions and military confrontation environments, is characterized by a different nature from those previously presented.

We can define the electromagnetic space as *the field of existence of electronic and electromagnetic phenomena*, which are used in the current struggle for:

- data and information exchange (generally C2);

- intelligence collection (ISR);
- radionavigation, directing and striking.

The importance of this battle space is not secondary. More often than not, the action aimed at disabling the adversary's command and control system is subsumed under this framework.

Electromagnetic space is defined as a space with several characteristics. First, although chronologically electromagnetic space as a battlefield dimension predates airspace, the latter matured more quickly as the fundamental environment of combat actions, the actions of aviation and anti-aircraft systems having a much more relevant and decisive character than electronic warfare actions in the Second World War.

The electromagnetic space constitutes the environment in which electronic and/or electromagnetic signals are produced and evolve. From a kinetic point of view, the three dimensions of physical space are conquered and occupied.

The actions of electronic warfare carried out in armed conflicts after the Second World War can be considered the historical consequences of the research crowned with spectacular results from the period 1939-1945. Although electronic warfare traces its beginnings to 1905 (the Russo-Japanese conflict), it can be considered that the first battle in which the practical dominance of electromagnetic space resulted in victory was probably the Battle of the Atlantic, in which electronic anti-submarine warfare measures allowed the British and Americans to destroy German U-boats, based on the high-frequency radio messages they transmitted daily to their bases. Each of the subsequent armed conflicts has led to the increasingly accelerated configuration of the electromagnetic space as a component of the battlespace that must be conquered and dominated before the actual battle in order to achieve military success.

On the other hand, the electromagnetic space constitutes the environment in which electronic and/or electromagnetic signals are produced and evolve. From a kinetic point of view, the three dimensions of physical space are conquered and occupied. The electromagnetic space is conquered, dominated and used for the benefit of one's troops through the use of signals. Moreover, the electromagnetic space determines a particular threat, different from the common threat of physical destruction, which it does not exclude: *"The destruction or physical suppression of electronic defence is the destructive action of electronic warfare that involves the employment of weapons that use direct electromagnetic energy or weapons directed*

on an electromagnetic beam, in order to remove from combat or damage the electronic equipment of the adversary" (Joint Publication 3-13.1, 2012, p. IV-6).

The electromagnetic threat is a specific threat of ISR systems that affects only electronic devices involved in communications and obtaining data and information. According to the sources devoted to the field but also to the latest published articles, it is stated that immediate warnings about threats and updates on targets are provided by – SIGINT (Signals Intelligence) which is made up of two components, ELINT (Electronic Intelligence) and COMINT (Communications Intelligence). *"ELINT is information about enemy threats and capabilities of systems such as radars, surface-to-air missile systems, and non-voice data links. It also provides accurate location information. However, it is susceptible to deception and has the disadvantage that it can only intercept signals in direct line of sight. COMINT provides information about enemy intentions and helps determine the enemy's command and control structure. For tactical military commanders, SIGINT operations include a dynamic update capability in the execution phase of military operations, particularly in direct support of combat aircraft"* (Wildenberg, 2023, pp. XV-XVI).

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The need to dominate the electromagnetic space, i.e. to possess electromagnetic superiority, becomes obvious if the following arguments are considered:

- obtaining freedom of action and ensuring execution capacity are seriously compromised in the event of inactivation of C2 elements;
- surprise, security, coordination and flexibility are difficult to implement in the presence of a hostile electromagnetic spectrum;
- the importance of defining the target, any element of the ISR field being difficult to replace regardless of the moment of the action;
- the importance and especially the volume of electronic and electromagnetic threats have increased considerably, being possible materialized in:
  - detection, interception and radio bearing capability that can be provided by airborne or aerospace platforms;

- disruption of own signals by the enemy;
- the continuing danger of electronic disinformation;
- the threat of physical destruction that radiation can cause to electronic devices (there is the possibility of concentrating enough electromagnetic energy to cause the remote destruction of any type of means).

The struggle for electromagnetic superiority stimulates the dynamics of concepts, forms and methods of use of forces, the emergence of new weapons and specialties. The scale, diversity, subtlety, confidentiality and efficiency of actions in the electromagnetic space determined the development of a new concept for the development of electronic warfare. It describes and highlights a specific confrontation, using electronic and electromagnetic signals as a form of action in the latest conflicts.

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It can be argued that electronic warfare, unlike kinetic warfare, is a one-way confrontation. Electronic warfare structures always represent the aggressor. They carry out offensive actions, including for the search, processing and dissemination of the obtained information. Electronic systems are always targets of electronic warfare structures. They implement electronic protection measures able to electronically/electromagnetically protect their own signals.

There are interesting studies and scientific concerns exploring the practical realities arising from the use of geolocation for electronic warfare in real-world systems. Thus, we are interested in the target position, errors in sensor position, orientation or velocity, and the impact of repeated measurements over time. The problems that can be solved have direct relevance to accurately locating and tracking UAVs, aircraft and ships (O'Donoughue, 2022).

Another important feature is that signals are generated in the electromagnetic space, while the equipment and devices that produce them are in the physical space. Consequently, electronic warfare systems, like communications and ISR systems, are subject to both the kinetic threat resulting in physical destruction, specific to physical space, and the specific threat of electromagnetic suppression, much more common to electromagnetic space. Thus, the resilience capacity of the operational and tactical echelons, which exploit these systems,

is always linked to this double threat. *"Electronic warfare actions, especially at the tactical level, can be used effectively to reduce an adversary's effectiveness"* (Poisel, 2013, p. 1).

Electronic superiority can be defined as the difference between the quantitative and qualitative level of opposing adversaries in electromagnetic space. By extension, it follows that electronic supremacy represents the moment when one of the adversaries has a clear superiority in means of electronic warfare (especially electronic attack), having secured the initiative and the possibility of carrying out its actions in the electromagnetic space, without a strong response, while the adversary cannot act systematically and organized with its own electronic means.

In modern military confrontations, electronic supremacy is achieved by gaining supremacy in electromagnetic space, which is an essential factor in the success of actions conducted in all environments. *"In modern radars, filtering, detection, and signal and data processors are implemented using digital techniques"* (De Martino, 2018, p. 39).

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Depending on the extension in time, space and in the electromagnetic spectrum, electromagnetic supremacy can be:

- strategic (comprising the entire theatre of military actions, for the entire duration of strategic operations and the entire electromagnetic space used by the parties in conflict);
- operational (comprising important areas in the theatre of military action, long periods of time and wide but compartmentalized frequency bands);
- tactical (comprising districts, time periods and a limited frequency spectrum, but sufficient for a tactical level action).

The struggle to achieve and maintain electromagnetic supremacy encompasses:

- neutralizing the opponent's electronic means, including through their physical destruction;
- electronic protection of own forces;
- keeping the initiative in managing the electromagnetic space;
- ensuring the *electromagnetic surprise* of the adversary and preventing its production by the adversary among its own forces.

Supremacy in electromagnetic space can be achieved, even when the technological level is not very high, by:

- the correct identification and management of threats in the electromagnetic space;
- ensuring the flawless functioning of communications and electronic warfare systems;
- requisitioning performance categories of technology from other users (including captured performance technology);
- the skilful management of the electromagnetic space, in spectrum and time, for the benefit of one's own forces, through:
  - rigorous planning of all emissions;
  - strict management of the emission power regime;
  - thorough organization of radio traffic;
  - simultaneous use of several frequency ranges;
  - close collaboration between structures capable of using the electromagnetic space;
  - exercising competent and efficient control, both administratively and operationally;
  - impeccable execution of work in the electromagnetic space by all users and efficient use of allocated frequencies;
  - the high level of staff training;
  - integration of electromagnetic space actions in all operations and ensuring effective and complementary support between structures, weapons and specialties.

The implementation of high-performance electronic means is one of the necessary conditions for ensuring freedom of action in the electromagnetic space and creating the premises for the prevention of electronic surprise.

However, in order to achieve electromagnetic supremacy, the technological level of the means used, as well as the degree of their integration into the systems of conducting combat actions, remain fundamental issues. The implementation of high-performance electronic means is one of the necessary conditions for ensuring freedom of action in the electromagnetic space and creating the premises for the prevention of electronic surprise. *"Successful electronic warfare techniques require mature, efficient, high-power, high-frequency, and reliable electronic devices, where the choice of enablement technology depends on the scope of application"* (Lambrechts, Sinha, 2017, p. 5).

There is a growing interest in electronic warfare (EW) in space due to the strategic advantages that satellites provide. Due to their elevated

positions, they can see a great distance and remain operational for long periods. Although satellites can be kinetically attacked, it is a big problem to do so; they are few and far between. This makes them valuable as EW platforms (Adamy, 2021).

ELECTROMAGNETIC SURPRISE – THE NECESSARY ELEMENT TO ACHIEVE SUPREMACY IN THE ELECTROMAGNETIC SPECTRUM

Electromagnetic surprise is the result of an action designed, planned, organized, conducted and executed in such a way as to have an unexpected character for the adversary, for which it is not prepared, or to put it in a position to identify with difficulty the necessary countermeasures.

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Being an important principle of military strategy, surprise, in general, and electronic surprise, in particular, contribute substantially to the achievement of success in military actions. Being distinctly different from kinetic capture, through combat actions, electronic capture has a number of particularities:

- *it is highly technological, digitized, cybercrud, automated;*
- *it depends on a number of physical phenomena and processes (wave and corpuscular aspect of electromagnetic radiation, propagation and classification of waves, etc.);*
- *it is confidential, subtle and generally effective;*
- *it requires serious scientific training of those who conceive, plan, organize and manage it, as well as perfect professionalism of the executors, who are also required to have training at the highest level;*
- *can cause greater damage than the physical impact (destruction) of predominantly energetic weapons (aircraft, artillery, tanks etc.);*
- *it is effective at big distances and at extremely high speeds, beyond borders or contact lines.*

Electronic capture can be *strategic, operational* and *tactical* and is achieved through:

- preserving the confidentiality of the conception of the actions, in general, of the use of electronic means, in particular;

- misinforming the adversary about one's own intentions with the help of *false electronic animation* of the area of responsibility;
- the covert preparation and timely triggering of the electronic attack;
- executing manoeuvres in time, space, and the electromagnetic spectrum, as well as electronic attack where the adversary least expects it;
- the use of new means and methods of combat, less known by the opponent;
- combined use of the effects produced by heavy weather conditions, darkness, reduced visibility, inaccessible terrain, actions of special forces etc. with those specific to electromagnetic space;
- ensuring a constant level of traffic of electronic means throughout the preparation and implementation of the actions;
- the rigorous application of electronic masking measures by all users of the electromagnetic space.

Electronic capture can be strategic, operational and tactical and is achieved through the rigorous application of electronic masking measures by all users of the electromagnetic space.

In order to avoid electronic surprise, a permanent monitoring of the electromagnetic space is necessary, the identification and timely solution of threats in the electromagnetic space (priority of the immediate ones), maintaining a high response capacity of the forces (especially those of electronic warfare), the execution of certain actions dynamic and complex for electronic coverage of areas of interest and responsibility, thwarting the adversary's electronic disinformation actions, thorough organization of combat support and assurance.

Electromagnetic spectrum management (EMSM) is crucial to success on the modern battlefield. An example can be the following: In 2020, the Secretary of Defence, Hon. Mark Esper wrote: *"These challenges (from similar or near-echelon adversaries) exposed the intersectional dependence of US forces on EMS"* (O'Donoughue, 2022, p. 1). Later in that document, he introduced a significant organizational change in the way the United States approaches EMS Operations (EMSO). These doctrinal and policy changes underscore what the tone means for the importance of Electronic Warfare (EW) as a core component of modern military operations.

Impeccable logistics, firm leadership and discipline in the use of electromagnetic space must also contribute to the prevention

of electronic surprise as a premise and element of general surprise. At this time, the realization of electronic surprise is still difficult to achieve. The measures permanently executed, since peacetime, by all modern armies (and not only), determine a high level of difficulty in terms of meeting this end.

From this perspective, electronic warfare, within the modern actions of the third millennium, will be no less than ground forces, aviation or navy, whose operations must accompany them permanently, subtly and confidentially, as a power multiplier, as the main source of information and effective force support.

CONCLUSIONS

The nature of the electronic warfare (EW) domain has changed in recent years and is in a state of accelerated change.

Important changes in the field of electronic warfare include:

- recognizing the electromagnetic environment as a distinct battlespace;
- new and extremely dangerous guided electronic weapons;
- new technologies that affect both the accuracy and lethality of weapons (Adamy, 2015).

Electronic warfare, within the modern actions of the third millennium, will be no less than ground forces, aviation or navy, whose operations must accompany them permanently, subtly and confidentially, as a power multiplier, as the main source of information and effective force support.

Discussions about their role lead to new weapons but also to the nature and effectiveness of EW measures to counter these weapons. The challenges of electromagnetic space go far beyond the military battlespace. Electromagnetic space is repurposed for commercial mobile broadband technologies to support economic growth and prosperity, which further limits freedom of action in the military domain. These technologies, while representing new opportunities for the economy, also present new challenges in the competition continuum as the electromagnetic operational environment becomes increasingly crowded, contested and constrained (i.e., complex).

Supremacy in the electromagnetic spectrum requires the collection, analysis and validation of robust information in the following key areas: electromagnetic spectrum sensors, communications, data links, radars, jamming, directed energy and infrared systems, engineering data describing the performance, characteristics and signature information of associated equipment, weapons and platforms, combat support data, and modelling and simulation support.

Both traditional overt actions and clandestine employment offer extensive options for the party possessing electromagnetic supremacy. Electromagnetic supremacy provides capability and potentially persistent access to targets at high speeds where many other capabilities require extensive time, resources and troop movements to be used.

Due to the multiple means of research available to a potential adversary today, it is no longer possible to mislead him by unilateral measures, and an ingenious combination of them is necessary so that the adversary receives the same false data from as many sources as possible can be superimposed on effective concealment measures. On the other hand, *"vulnerabilities increase in direct proportion to the technological level implemented in the construction and operation of equipment (especially digital)*" (David, 2021).

Electromagnetic supremacy brings important advantages to any costing strategy. By developing innovative asymmetric electromagnetic spectrum capabilities, any state can protect its own costly capabilities from disruption or attrition, while denying or degrading the effectiveness of modern adversary systems.

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