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ANALYSIS OF TECHNICAL CHARACTERISTICS OF THE RADIOELECTRONIC WARFARE SYSTEMS

Given the conduct of the Joint Forces operation in eastern Ukraine and as a result of the full-scale armed aggression of the russian federation, the issue of analyzing the technical characteristics of electronic warfare equipment is relevant. At the same time, a major increase in combat capabilities in the near future will be possible due to the use of intelligent troop and weapon control systems, as well as the use of weapons that use non-traditional means of influencing the enemy. During the analysis of modern methods of electronic warfare, it was found that this industry is becoming increasingly important in the context of modern military conflicts and cybersecurity threats. The use of artificial intelligence, cyber measures and the latest technologies of electronic warfare necessitates the constant improvement and adaptation of electronic warfare strategies. Both russian and Western methods of electronic warfare are characterized by a high level of technical complexity and effectiveness. Consideration of Western approaches indicates the active role of Western countries in the development and implementation of innovative technologies for controlling and countering electronic threats. The development of electronic warfare systems is becoming more effective, fast-acting, economically profitable, and the only possible means of eliminating the technical advantage of the opposing side in the information and technological sphere. Electronic warfare is an important component of modern combat, and its importance will only grow in the future. In particular, the development of new technologies will allow the creation of more effective electronic warfare means, which will have a significant impact on the course of hostilities. Therefore, the article analyzes modern electronic warfare systems used in the Ukrainian-russian war. The main tactical and technical characteristics of these electronic warfare systems are highlighted. The issue of detecting unmanned aerial vehicles by various electronic warfare methods is also highlighted.

Keywords: modern electronic warfare systems, military conflicts, electronic confrontation, innovative technologies, air defense, radar reconnaissance means, unmanned aerial vehicle.

Introduction and problem statement. In the modern world, electronic warfare systems are extremely important for overcoming terrorist threats and other forms of aggressive activity. In particular, the experience of conducting combat operations confirms that the effective use of unmanned aerial systems affects the success of combat and special operations.

These systems are used not only for reconnaissance and surveillance of the battlefield, but also for delivering explosive devices to objects. The main advantage of electronic warfare systems is their ability to remotely influence enemy radio systems, such as disabling their components or silencing certain areas of the spectrum.

Research in this area is always relevant, since the competition between radio suppression and protection systems is constantly progressing. Analysis of electronic warfare systems, in particular Ukrainian and russian, together with the study of modern unmanned aerial vehicles and their classification, is an important stage in understanding modern capabilities and improving security measures. In particular, taking into account the use of amateur drones, such as the well-known DJI companies, determines the need to develop means of combating them. So, this article analyzes modern electronic warfare means, their characteristics and considers their impact on unmanned aerial vehicles, which is a relevant area of research due to the increasing use of these technologies in combat conditions.

Analysis of research and publications. At the present time, electronic warfare is gradually becoming a characteristic form of combat operations aimed at achieving an advantage or preventing

the enemy's advantage in the information component of armed combat. This is achieved by using electronic means. Today, it can be noted that the successful solution of electronic warfare tasks can determine the success of the entire operation and even a local war or armed conflict as a whole. Nowadays, electronic warfare continues its gradual development and improvement, in particular, taking into account new technologies such as quantum informatics, artificial intelligence, nanotechnology and others. Also in recent years, innovative electronic warfare technologies have appeared, among which it is worth noting: adaptive radar jamming, which can automatically adjust to the frequency and parameters of the enemy radar signal, creating an effective jamming signal; stealth technology, which reduces the visibility of an object for radars and other electronic means due to its shape, materials, coloring and other parameters; coherent radar, which uses coherent radiation to increase the accuracy and resolution of target detection and location; computer network operation.

Thus, electronic warfare has become an integral part of military strategy, evolving along with changes in technology and military conflicts. Electronic warfare includes a set of measures and means aimed at influencing the enemyapos;s electromagnetic environment in order to ensure an advantage in combat operations.

The most famous Ukrainian electronicwarfare systems include: "Bukovel" – an electronic warfare complex designed to suppress enemy radars; "Kolchuga" – an electronic warfare complex designed to actively interfere with enemy radars; "Nota" – an electronic warfare complex designed for direction finding and radio reconnaissance; "Antey" – an electronic warfare complex designed to protect aircraft from radar missiles. Today, Ukraine is armed with a wide range of electronic warfare systems, which are designed to: suppress enemy radars; disruption of enemy communication systems; misleading enemy electronic equipment; physical damage to enemy electronic equipment. Ukrainian electronicwarfare systems were actively used in the war in Donbas and during the full-scale armed aggression of the russian federation. With their help, the Ukrainian troops managed to: reduce the efficiency of russian radars; disrupt russian communication systems; mislead russian electronic equipment; protect Ukrainian aircraft from radar missiles [2–5]. Based on the experience of waging the russian-Ukrainian war since February 2022 and in order to unify and summarize data on various electronic warfare means according to their purpose, we present a classification of electronic warfare means used by the Armed Forces of Ukraine and the Defense Forces of Ukraine and other military formations according to their main classes and types [1], [6], [7].

Electronic jamming equipment installed on vehicles used by the Armed Forces of Ukraine and the Defense Forces of Ukraine [1].

REW-complex “Khortytsia-R” (year of manufacture: 2017)

Country of manufacture	**Crew, people**	**Basic chassis**
Ukraine	3	IVECO
Operating frequency range, MHz		25–6 000
Suppression range, km	satellite navigation systems	≥30
	data transmission channels	≥15
Obstacle installation range, km	satellite navigation systems	≥30
	data transmission channels	≥17

Figure 1 - REW-complex “Khortytsia-R”

Complex REW R-330UM “Mandat-M/B1” (year of manufacture: 2014; modernization: 2020)

Designed for detection and radio suppression of communication lines, both with fixed operating frequencies and with software adjustment of the operating frequency.

<table>
<tr><th>Country of manufacture</th><th>Components of the complex</th><th>Shortwave, ultrashortwave R-330RD (ME)</th><th>Shortwave R-330SW1 (ME)</th><th>Ultrashortwave1 R-330USW1 (ME)</th><th>Ultrashortwave2 R-330USW2 (ME)</th></tr>
<tr><td>Ukraine</td><td>Quantity, units</td><td>1</td><td>2</td><td>2</td><td>2</td></tr>
<tr><td colspan="2">Basic chassis
KraZ-260</td><td colspan="4" rowspan="6">  </td></tr>
<tr><td colspan="2">Operating frequency range
shortwave, ultrashortwave</td></tr>
<tr><td>Effective suppression of radiocommunication channels, km</td><td>≥80</td></tr>
<tr><td colspan="2">Detection range, km</td></tr>
<tr><td>by depth</td><td>behind the front</td></tr>
<tr><td>60</td><td>90</td></tr>
</table>

Optical-electronic countermeasure complex “Kashtan-3(M)” (year of manufacture: 2006)

The complex is designed to protect ground targets from high-precision laser-guided weapons – missiles, aerial bombs with semi-active laser homing heads.

<table>
<tr><th>Country of manufacture</th><th>Unit weight, t</th><th>Basic chassis</th><th rowspan="2">Working wavelength, mm</th></tr>
<tr><td>Ukraine</td><td>20</td><td>ZIL-131 / KraZ</td></tr>
<tr><td>Range, km</td><td colspan="2">Maximum speed, km/h</td><td>1,06</td></tr>
<tr><td>500</td><td colspan="2">75</td><td>360</td></tr>
<tr><td rowspan="2">Observation angle range, degrees</td><td>in azimuth</td><td></td><td>15±90</td></tr>
<tr><td>by the angle of the moon</td><td></td><td>≥15</td></tr>
<tr><td colspan="3">Angular coordinate determination error</td><td></td></tr>
</table>

Figure 2 - Optical-electronic countermeasure complex “Kashtan-3(M)”

Electronic warfare complex “Liman” (year of manufacture: 2000)

Recognized for radio jamming of aviation control lines.

Country of manufacture	**Components of the complex**		**p.k. “Liman - PK”**		**s.p. “Liman-P1”**		**s.p. “Liman-P2”**	
Ukraine								
Basic chassis	Total number of components in the complex, units.			12	**Unit weight, t**	15	Range, km	500
Kamaz / KraZ								
Maximum speed, km/h	60	Operating frequency range, MHz	ultrashortwave	Range, km	detection		450	
					suppression		≥200	
Types of work					Operating modes			
centralized	according to the commands of the control center		off-line		active		passive	

Portable electronic suppression equipment used by the Armed Forces of Ukraine and the Defense Forces of Ukraine.

Electronic warfare complex “Enclave” (year of manufacture: 2016)

Country of manufacture	Ukraine
Components of the complex	–
Appointment	combat against UAVs
Operating frequency range	ultrashortwave
Suppression range, km	20–40
Output power, W	20
Power consumption, W	150

Electronic warfare complex “Garant(-M)” (year of manufacture: 2014)

Country of manufacture	Ukraine
Components of the complex	UAVs -1/2/3/4
Appointment	suppression of funds
Operating frequency range	shortwave, ultrashortwave
Suppression range, km	0,075–0,5
Output power, W	700

Power consumption, W	To 1 500	

Complex of satellite countermeasures "Kupol" (year of manufacture: 2018)

Country of manufacture	Ukraine	Unit weight, t	30	
Operating frequency range, MHz			shortwave, ultrashortwave	
Output power, W	20	Number of channels, units	2	
Suppression distance, km		with directional antennas	≥15	
		with directional antennas	≥250	
Power consumption, W			150	

Radar reconnaissance equipment installed on transport vehicles and used by the Armed Forces of Ukraine and the Defense Forces of Ukraine.

REW-complex RP-3000 "Plastun" (year of manufacture: 2018)

Country of manufacture	Crew, people	Time / duration	autonomous operation, hours	≥8
			deployment, min	≥20
Ukraine	–	Application radius, km		≥15
Operating frequency range, MHz		ultrashortwave		
Average direction finding error, degrees	in the range of 25–90 MHz	1,2		
	in the range of 90–525 MHz	0,8		
	in the range of 525–3,000 MHz	1		

Figure 3 - REW-complex RP-3000 "Plastun"

Multifunctional radar reconnaissance equipment installed on transport vehicles and used by the Armed Forces of Ukraine and the Defense Forces of Ukraine.

The most famous Ukrainian radioelectronic warfare complex include:

"Bukovel-AD" – an radioelectronic warfare complex designed to suppress enemy radars;

"Jeb" – mobile ground reconnaissance radioelectronic warfare complex;

"Nota" – an radioelectronic warfare complex designed for direction finding and radio reconnaissance;

"Cloud-2" – designed to detect UAVs using passive radar (radio direction finding);

"Polonaise" – intended for combating UAVs, installations on the mobile platform.

As of today, almost the entire share of EW production is “closed” by private companies. Here we can note the tactical complex “Bukovel-AD R4” from Proximus LLC. It works great on enemy UAVs at a distance of 15–20 km. This complex can track them at a distance of 70–100 km.

To understand that “Bukovel-AD R4” is quite effective, it is worth paying attention to the fact that it was purchased by the Moroccan Armed Forces in 2019. Proximus LLC is also developing a passive broadband RF detector DW-4. The system can provide an effective detection range of up to 50 km and operates in a 360-degree sector. To increase the accuracy of detection, the system uses processed signals from all 4 antenna sectors simultaneously.

In addition, at the end of 2023, the Ministry of Digital Transformation showed the Ukrainian development of the electronic warfare complex, created as part of the Brave1 regular program – Piranha AVD 360. This complex creates a protective dome up to 600 meters around itself. Piranha AVD 360, which has already successfully passed field tests, has the ability to block the channels of satellite navigation systems, for example, the russian GLONASS. It is impossible not to mention the modern domestic development of the electronic warfare system – "Pokrova". Its work is that it replaces the satellite radio navigation field and suppresses satellite radio navigation not only along the line of combat contact, but also in most of Ukraine.

There is almost no official information about it, but earlier the former spokesman for the Air Force of the Armed Forces of Ukraine Yuriy Ignat reported that it is already successfully operating at the front.

The "Pokrova" complex works using spoofing technology. its essence is to replace satellite signals. This, in turn, confuses the drones' navigation devices. As a result, this leads to a deviation from the route and they either fall or fly past the target. This makes it possible to work effectively not only on different parts of the front, but also in the rear, covering important infrastructure and strategic objects. "Pokrova" has already reliably proven itself in work against russian "shaheeds/geraniums".

There is also an electronic warfare device in the Ukrainian arsenal – "Tornado-4" from the domestic company ArmaTronix. "Tornado-4" is designed for a short range and is quite portable. It can counteract various types of drones - from reconnaissance to FPV drones, and its main task of protection is the location of military and crossings.

As for the range, it is up to 700 meters, and its battery is designed for 4 hours of operation. It is also worth noting the reconnaissance system – Griselda. It is being developed by the Ukrainian defense-tech Brave1 together with several units of the Special Operations Forces, the Armed Forces of Ukraine, the Security Service of Ukraine and the Ministry of Defense. This system is built on the basis of artificial intelligence. It collects, processes and transmits huge amounts of information in the form of intelligence to the military. In 2022, the system processed almost 250 thousand different pieces of information, and in 2023, the military received about 4 thousand targets every week with its help. Only 28 seconds pass from the moment the information is received to its processing.

Conclusions and prospects for further development. The article is intended to provide comprehensive information about the main electronic warfare systems used during the Ukrainian-russian war. It examines in detail the technical characteristics, principles of operation, tactical capabilities and practical application of various electronic warfare systems. This material will be useful for military specialists, analysts, researchers in the field of military equipment and everyone who is interested in modern means of ensuring electronic superiority on the battlefield. The prospect of further research is to study both Russian and Western methods of electronic warfare.

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АНАЛІЗ ТЕХНІЧНИХ ХАРАКТЕРИСТИК СИСТЕМ РАДІОЕЛЕКТРОННОЇ БОРОТЬБИ

Враховуючи проведення операції Об'єднаних сил на сході України та внаслідок повномасштабної збройної агресії російської федерації, актуальним є питання аналізу технічних характеристик засобів радіоелектронної боротьби. Водночас основне підвищення бойових можливостей найближчим часом буде можливе за рахунок використання інтелектуальних систем управління військами та озброєнням, а також використання зброї, що використовує нетрадиційні засоби впливу на противника. У ході аналізу сучасних методів радіоелектронної боротьби виявлено, що ця галузь стає все важливішою у контексті сучасних військових конфліктів та загроз кібербезпеки. Застосування штучного інтелекту, кіберзаходів та новітніх технологій радіоелектронної боротьби зумовлює необхідність постійного вдосконалення та адаптації стратегій електронного протистояння. Як російські, так і західні методи радіоелектронної боротьби відзначаються високим рівнем технічної складності та ефективності. Розгляд західних підходів свідчить про активну роль країн Заходу у розробці та впровадженні інноваційних технологій для контролю та протидії електронним загрозам. Розробка систем радіоелектронної боротьби стає більш ефективною, швидкодіючою, економічно вигідною, а й і єдиним можливим засобом, який нівелює технічну перевагу протилежної сторони в інформаційно-технологічній сфері. Радіоелектронна боротьба є важливою складовою сучасного бою, і її значення буде лише зростати в майбутньому. Зокрема розвиток нових технологій дозволить створювати більш ефективні засоби радіоелектронної боротьби, які матимуть значний вплив на хід бойових дій. Тому у статті проведено аналіз сучасних систем радіоелектронної боротьби, які використовуються в українсько-російській війні. Висвітлені основні тактико-технічні характеристики цих систем радіоелектронної боротьби. Також висвітлено питання виявлення безпілотних літальних апаратів різними методами радіоелектронної боротьби.

Ключові слова: сучасні системи радіоелектронної боротьби, військові конфлікти, електронне протистояння, інноваційні технології, протиповітряна оборона, засоби радіолокаційної розвідки, безпілотний літальний апарат.