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Ensuring electromagnetic compatibility (EMC) for UAVs in a metropolitan area

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Abstract. Since the mid-2000s, reports began to regularly appear in the media about the unauthorized use of unmanned aerial vehicles (UAVs) in specially controlled areas: at airports, at military facilities, against critical industrial infrastructure, etc. The use of UAVs in urban environments adds the problem of noisy communication channels, and increases the risk of system failures, since not only the devices themselves, but also people or private property may be damaged. These factors raise the problem of electromagnetic compatibility of navigation, communication and information storage devices used. Currently, small UAVs are widely used for unauthorized surveillance of important objects, carrying out terrorist attacks and sabotage, carrying prohibited cargo (weapons, drugs), as well as in military affairs. In this regard, the task of countering UAVs, and especially small UAVs, has become urgent. At the same time, the problem of EMC of UAVs, and, in particular, small UAVs, is extremely complex, multifaceted and has not yet been effectively solved.

Keywords: *UAV, EMC, EMF.*

1. Introduction

The purpose of the work is to analyze various methods and means of UAV EMC.

The rapid development of unmanned aerial vehicle (UAV) systems in Kazakhstan and abroad and the development of radio electronics force us to constantly reconsider the requirements for the communication channel between the UAV and the ground control complex (GCU).

The direction of radio electronics that ensures the simultaneous and joint operation of various radio engineering, electronic and electrical equipment is called electromagnetic compatibility (EMC) of radio electronic equipment (REA).

The aggravation of the EMC problem is due to the following reasons:

- increase in the total number of simultaneously operating radio devices, especially those installed on moving objects;
- increasing the power of radio transmitters, when some types reach tens of megawatts;
- expansion of the frequency band used by many modern radio devices;
- increasing the load of the radio frequency range;
- automatic control, diagnostic control, etc. based on analog and digital technology (computers and special processors), widespread introduction of electronic tools;
- increasing the equipment of electronic devices of moving objects, especially ships, aircraft and spacecraft, increasing the density of the equipment circuit;
- deterioration of operating conditions for radio-electronic equipment installed on aircraft located in the line-of-sight zone of ground-based radio-electronic equipment located over a large area;
- expansion of mobile radiotelephone communications.

2. Sources of EMF

In the case of small UAVs (take-off weight up to 5 kg), due to restrictions on the size and weight of the transceiver equipment, it is rational to use a single radio communication channel for transmitting command and telemetry data and payload data. The only additional radio communication channel is the SAS data line. To meet the requirements for communication channel capacity when transmitting both telemetry data and payload data, it is necessary to expand the frequency band of the transceiver equipment and use spectral-efficient modulation methods, which leads to increased requirements for the signal-to-noise ratio (SNR) at the receiver input, reducing the range of the radio system, increasing the probability of a bit error, etc.

Sources of electromagnetic interference are devices of any class that emit electromagnetic radiation. This includes devices that are not designed to emit electromagnetic waves (such as engines, ignition systems, etc.). Receivers of electromagnetic interference are all devices that change the values of their parameters (reversibly or irreversibly) under the influence of electromagnetic interference.

Unintentional electromagnetic interference (UNEMI) is considered to be any radio interference created by a source of artificial origin, not intended to disrupt the functioning of radio-electronic equipment. Often, instead of radio interference, they talk about electromagnetic interference. Electromagnetic interference is defined as an undesirable effect of electromagnetic energy that deteriorates or may deteriorate the quality of operation of electronic devices. We can think of radio interference as electromagnetic interference in the radio frequency range. Ensuring electromagnetic compatibility (EMC) and protection from the effects of electromagnetic interference is of great importance in electrical complexes and systems of aircraft and spacecraft (ACVs).

In modern spacecraft and aircraft, on-board instruments and devices and systems may be subject to electromagnetic influences, which deteriorate the quality of their functioning and can lead to long-term failures and malfunctions. The performance of the aircraft as a whole depends on the proper functioning of on-board instruments and devices.

At the moment, there are certain standards for the production of equipment and cable networks intended for aircraft, as well as standardized methods for ensuring and testing protection against various types of interference. However, technology is constantly evolving, and much of the effort is aimed at reducing power consumption and reducing the size of electronic components. Miniaturization and cost-effectiveness of electronic systems, in turn, gives rise to new EMC problems and greatly aggravates old ones, since the susceptibility of electrical systems to various types of electromagnetic influences from external and internal sources increases significantly. In addition, the number of external artificial sources of electromagnetic influences around is constantly increasing.

This leads to a sharp increase in the probability of aircraft failure from electromagnetic influences in the form of electromagnetic fields emitted not only by natural, but also primarily by artificial sources. The increasing sensitivity of on-board electronic equipment to electromagnetic influences requires a more attentive attitude to the issues of increasing noise immunity and noise immunity [1].

Existing methods for ensuring noise immunity and noise immunity are not always sufficiently effective in the complex electromagnetic environment created by modern technical means of generating electromagnetic influences.

To increase noise immunity and noise immunity, additional research is required on technical parameters, such as transition resistance and shielding efficiency, research on the paths of penetration and propagation of electromagnetic influences in the structure and electrical circuits of aircraft.

Aircraft are complex multi-component technical devices and have many systems in their structure.

One of these is the on-board cable network of the aircraft (BCS LA). The on-board cable network performs the function of communication between on-board systems and devices, provides power supply and information exchange. Electromagnetic influences influence through the cable network all on-board instruments and devices of the electrical complex of the aircraft and, consequently, the quality of functioning of all aircraft systems.

The most vulnerable to interference penetration are the junctions of cable shields with the electrical connectors of the on-board cable network [2-3].

The study of existing methods of electromagnetic shielding and the study of the paths of penetration and propagation of electromagnetic influences in the form of high-frequency electromagnetic fields in the aircraft design allows us to evaluate the effectiveness of the applied technical means of protection and develop recommendations for increasing noise immunity and noise immunity.

The results of the study make it possible to develop methods and technical means for increasing the effectiveness of shielding by complementing existing traditional methods with new approaches to solving problems of protection from electromagnetic influences.

Interference affecting aircraft can be divided into interference of natural origin and interference of artificial origin. Sources of natural EMFs affecting aircraft include lightning discharges [4], electrostatic discharges and electromagnetic radiation from the atmosphere and space, as well as UFOs.

Sources of artificial EMF, in turn, are divided into sources of intentional and interference. Unintentional sources of EMF include various transport, industrial and industrial systems, communication and navigation systems, various radio transmitting and radar stations.

Sources of intentional EMF fall into the category of electronic warfare (electronic warfare) equipment and are used for the targeted disabling of aircraft technical equipment. These can be ultra-short pulse generators or explosive magnetic generators (ultra-wideband pulse generators).

Unintentional sources include interference created by some technical means of the aircraft affecting others.

Natural sources of EMF

- Lightning discharge is the most dangerous natural phenomenon for aircraft. A lightning discharge is a source of powerful electromagnetic interference in the form of a pulsed current (lightning) in the atmosphere and the accompanying electromagnetic field. A lightning discharge begins with a leader stage, which occurs at voltages of the order of 1-3·106 V/m, followed by the main discharge, which is the main source of a powerful pulsed electromagnetic field. Often the discharges are multiple (on average up to 15) with time intervals of 0.001-0.5 s and subsequent discharges are weaker

- Electrostatic discharges may occur on board atmospheric and

spacecraft due to their general and/or differential charging due to the triboelectric effect, i.e. friction of conductive and dielectric surfaces of its structure with air, precipitation particles (snow, rain), dust.

Corona discharges are pulses with an amplitude value of ~10 mA, a front of ~10 ns and a duration of ~100 ns. Corona discharges create broadband radiated electromagnetic interference, which can significantly impair the performance of radio-electronic equipment. Radiated interference arising from spark breakdowns of dielectric surfaces with a frequency spectrum of ~10-1000 MHz can also affect the operation of radio-electronic devices of aircraft.

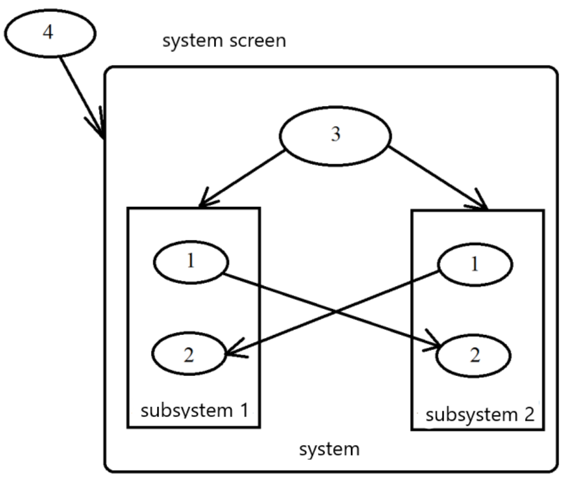

Figure 1. Illustration of inter-system EMC system, subsystems, 1 – intra-system sources of interference, 2 – intra-system interference receptors, 3 – general system source of interference, 4 – source of interference outside the system

Intersystem EMC implies the presence of interference sources outside the system. In this case, it is necessary to ensure joint operation of the system with sources of interference, Figure 1. At the same time, the electromagnetic impact passes through a number of barriers at the system and intersystem levels, and a topological model can be constructed to consider this process.

REP means do not consume such material resources and require only energy supply, which can be stationary. However, as shown in [12], successful opening and suppression of navigation, control and radio communication channels does not guarantee that the UAV will stop its flight towards the controlled area.

It is the lack of an unambiguous response of UAVs to successful suppression that is a significant drawback of counter-UAV systems based on electronic warfare.

Other means, the principle of operation of which is based on the formation of directed EMR to cause damage to the targets - the means of FP EMR, do not have the above disadvantage.

FP EMP means have a large «area effect», ensuring a relatively effective termination of the flight of almost all UAVs that fall within their coverage area, regardless of their type, control mode (remote control or autonomous flight), or type of navigation system. The effectiveness of FP EMR is based on changes in the electrophysical parameters of semiconductor elements of numerous radio electronic devices (RES) operating as part of a UAV.

At the same time, the effectiveness of FP EMR means also has a downside. In particular, they are characterized by other significant disadvantages - the high power of the generated EMR and the difficulty of ensuring its «selectivity» in relation to the affected electronic devices. This acutely raises the issue of ensuring electromagnetic compatibility (EMC) of FP EMI equipment with other electronic devices as part of the UAV countermeasures complex.

For a comprehensive assessment of this method of damaging UAVs, we will consider the basics of functional damage to RES by microwave radiation, the currently available prototypes of similar means of FP EMR, on the basis of which we will evaluate the effectiveness of using these means of destruction against UAVs.

The main difference between EMR FP and REP is the physical principle of causing damage. In case of PT EMR, damage to the electronic devices is caused by an irreversible (catastrophic) or reversible (recoverable) change in the physico-chemical structure of the electronic devices elements due to the influence of electromagnetic fields on the materials included in electronic and semiconductor devices and other components of these systems.

The effect of PT EMR on RES is based on the possibility of changing the physico-chemical properties of electrical and radio materials when irradiated with strong electromagnetic fields.

Irreversible changes in the properties of a substance, leading to qualitatively new formations with a different electromagnetic structure, occur with significant energy of the impacting EMR.

When powerful microwave oscillations interact with the RES of a UAV, two main effects can be observed [6]:

1) induction of microwave power on circuit elements (terminals of semiconductor devices, printed conductors, etc.), which leads to electrical overloads;

2) direct interaction of microwave pulses with the structure and material of the semiconductor element.

The advantages of FP EMR mean when used against UAVs include the following:

- expanding the range of tasks to be solved due to the possibility of destroying non-emitting UAVs;
- versatility (the ability of EMP to hit a wide range of UAVs, while the effectiveness of defeating UAVs does not depend on their type, size, or functional purpose);
- out-of-band (the ability of EMR to penetrate inside the UAV's RES in addition to the bandwidth of its receiving paths of radio communication RES);
- effective impact on UAVs with high noise immunity to the use of traditional electronic warfare methods;
- rejection of complex means of analyzing and simulating signals to suppress the navigation and radio communication channel of UAVs, which are traditionally used in electronic warfare;
- reduction in some cases of requirements for the quality of target designation (by location, frequency range, operating modes), which is necessary to destroy enemy UAVs.

Promising samples of PT EMR means are based on the generation of a short-term high-power EMR pulse that can disable the electronic electronic devices that form the basis of the control system of any UAV.

3. Counteracting EMF

Medium and large class UAV communication systems are subject to more stringent requirements for operating range, noise immunity and bit error probability. In this case, it is possible and optimal to integrate several communication channels operating in different frequency ranges.

The use of multiple communication channels increases the reliability of the data transmission system and at the same time is redundant from the point of view of efficient use of the radio frequency spectrum. One of the ways to increase the efficiency of an integrated communication system is the adaptive operation of the system, which involves transmitting part of the payload data over command and telemetry communication channels, the volume of which varies depending on the current conditions of radio signal transmission.

As a rule, the maximum distance for direct radio communication between a civil UAV and a low-voltage control unit today is no more than 100 km. For command and telemetry communications over long distances, it is possible to use satellite communications. In this case, the data flow is limited to the minimum necessary information about the state of the UAV, the transmission interval of which can be, for example, from 30 to 300 seconds.

A promising direction in the development of communication systems with UAVs is the use of frequency ranges above 5 GHz. In this case, it becomes possible to transmit a large amount of payload data in real time (for example, these can be images from radiation sensors of various wavelengths). Factors that sharply limit the range of a radio communication system when using these ranges are the strong dependence of the propagation conditions of electromagnetic waves on weather conditions, the need for line of sight and the influence of multipath.

4. Conclusions

The article presents the results of an analysis of various methods and means of countering UAVs. The systematization is based on an analysis of open sources, which made it possible to reveal the main features of UAVs and their potential effectiveness when working against air targets of this type.

Thus, when designing communication systems and using new UAV systems in a metropolitan area, it is necessary to check the possibility of electromagnetic compatibility (EMC) of the designed system with other radio-electronic equipment. The task of ensuring EMC of radio-electronic equipment is to ensure that, when the appropriate conditions are met, mutual interference does not interfere with the normal functioning of other radio-electronic equipment and systems.

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Елордалық аймақтағы ұшқышсыз ұшу аппараттары үшін электромагниттік үйлесімділікті (ЕМС) қамтамасыз ету

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Аңдатпа. 2000 жылдардың ортасынан бастап бұқаралық ақпарат құралдарында ұшқышсыз ұшу аппараттарын (Ұшқышсыз Ұшу Аппараттарын) арнайы бақыланатын жерлерде: әуежайларда, әскери нысандарда, маңызды өндірістік инфрақұрылымға қарсы және т.б. рұқсатсыз пайдалану туралы хабарламалар үнемі шыға бастады. Қалалық ортада ұшқышсыз ұшу аппараттарын пайдалану шулы байланыс арналарының мәселесін арттырады және жүйенің істен шығу қаупін арттырады, өйткені құрылғылардың өздері ғана емес, адамдар немесе жеке меншік объектілері де зақымдалуы мүмкін. Бұл факторлар пайдаланылатын навигациялық, коммуникациялық және ақпаратты сақтау құрылғыларының электромагниттік үйлесімділігі мәселесін көтереді. Қазіргі уақытта шағын ұшқышсыз ұшу аппараттары маңызды объектілерді рұқсатсыз бақылау, лаңкестік шабуылдар мен диверсияларды жүзеге асыру, тыйым салынған жүктерді (қару-жарақ, есірткі) тасымалдау, сондай-ақ әскери істерде кеңінен қолданылады. Осыған байланысты ұшқышсыз ұшу аппараттарына, әсіресе шағын ұшқышсыз ұшу аппараттарына қарсы тұру міндеті өзекті болды. Сонымен қатар, ұшқышсыз ұшу аппараттарының, атап айтқанда, шағын ұшқышсыз ұшу аппараттарының ОӘК мәселесі өте күрделі, көп қырлы және әлі тиімді шешілген жоқ.

Негізгі сөздер: *ұшқышсыз ұшу аппараты, ОӘК, ЭҚК.*

Обеспечение электромагнитной совместимости (ЭМС) беспилотных летательных аппаратов в условиях мегаполиса

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Аннотация. С середины 2000-х годов в СМИ стали регулярно появляться сообщения о несанкционированном использовании беспилотных летательных аппаратов (БПЛА) в особо контролируемых зонах: в аэропортах, на военных объектах, против критически важной промышленной инфраструктуры и т.д. Использование беспилотных летательных аппаратов в городских условиях усугубляет проблему зашумленных каналов связи и увеличивает риск системных сбоев, поскольку могут пострадать не только сами устройства, но и люди или частная собственность. Эти факторы повышают проблему электромагнитной совместимости используемых устройств навигации, связи и хранения информации. В настоящее время небольшие беспилотные летательные аппараты широко используются для несанкционированного наблюдения за важными объектами, совершения терактов и диверсий, перевозки запрещенных грузов (оружия, наркотиков), а также в военном деле. В связи с этим задача противодействия беспилотным летательным аппаратам, и особенно малым беспилотным летательным аппаратам, стала актуальной. В то же время проблема электромагнитной совместимости беспилотных летательных аппаратов, и, в частности, небольших беспилотных летательных аппаратов, чрезвычайно сложна, многогранна и до сих пор эффективно не решена.

Ключевые слова: *беспилотный летательный аппарат, электромагнитная совместимость, ЭМП.*

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