Methods of protecting radio-electronic control systems from powerful electromagnetic interference

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Abstract. An analysis of methods of protecting control system equipment from powerful electromagnetic interference was done. The nature of possible damages of radio-electronic components under negative influence of electromagnetic fields was considered. All methods of protection against powerful electromagnetic interferences can be divided into three groups: structural, sheet-oriented and structurally functional. The most effective protection measures aimed at preventing possible damages were determined. The purpose of the paper was to consider thoroughly each of the existing methods aimed at increasing the resistance of radio electronic system to negative impact of powerful electromagnetic interferences.

1. Introduction
The radio electronic system is a technical basis of automation control of any sphere of life. High level of automation using modern information technology is the main feature of modern control systems. Feasibility of collection, processing and transfer of information are going through fundamental changes. The speed of processing of large volumes of information is increasing significantly while decision-making time is decreasing which allows proceeding to conceptually new methods of control in any spheres of life [1-3].

However, the intensive adaptation of modern information technologies amplifies their dependence on the operating hardness of control systems [1-8]. Control is realized through control means which include the communication system, automation systems and other special systems and means which ensure control process performance. The analysis of the research findings shows that semiconductor devices and integrated circuits are most vulnerable to electromagnetic influence. However, it is they, which are the basic components of modern systems and control means. By means of those components, the radio electronic system can function at a high rate of processing data, the amount of which is constantly increasing and makes it possible to reduce mass and dimensions parameters.

Semiconductor devices and integrated circuits work with signals, whose power level is $10^{-3} - 10^{-8}$ J. This led to considerable reduction of radio electronic system resistance to electrical overloads including pulse current and voltage induced in cable lines and feeder circuits. At that, the radio electronic system located in the body is a shield and, as a rule, it is insensitive to external electromagnetic interferences when connecting cables, loses its properties [1-14].

In connection with the increase in the density and power of electromagnetic radiation and a simultaneous continuous increase in the sensitivity of the developed equipment, there is a need to ensure...
stable operation of the radio electronic system in the conditions of exposure of powerful electromagnetic interferences. The probability of an adverse effect on the operation of a radio electronic system inadvertent interference of various origins is constantly increasing.

The protection of a radio electronic system should be built on the basis of their analysis as a system, which means a complex of individual elements performing a set of interrelated actions aimed at achieving a common goal.

The protection of a radio electronic device against the impact of the powerful electromagnetic interferences ensures its operation within the limits of the tolerance range of changing parameters set according to the conditions for maintaining the operability of the electronic zone.

When choosing measures to protect the radio electronic system from the adverse effect of the powerful electromagnetic interferences, it is taken into account that the threat of a dysfunction of the radio electronic system is usually not created by the powerful electromagnetic interferences itself, but by its interaction with antennas, communication lines and equipment conductors, in which the powerful electromagnetic interferences field is transformed into interfering voltages and currents.

Protection of radio electronic system against the impact of powerful electromagnetic interferences is based on:

- the use of methods that allow one to reduce the level of interference in the circuits of radio electronic facilities;
- the use of components of radio electronic devices possessing high resistance to the action of powerful electromagnetic interferences.

The main requirement for a protective element is to ensure its minimal impact on the operation of the protected device in the absence of powerful electromagnetic interferences.

Protection of the radio electronic system against the effects of powerful electromagnetic interferences is organized according to a stepwise principle. At the first stage, coarse protection is provided, reducing the level of disturbing voltages in the radio electronic system circuits to acceptable values. At the second stage, noise reduction is carried out with the help of filters and corrective circuits. It is possible to ensure high quality of the operation of the radio electronic system in the conditions of exposure to the powerful electromagnetic interferences only by applying special protection measures.

The use of certain protection measures in a particular radio electronic system depends largely on the permissible levels of interference in their circuits. The higher the level of interference, the less the protection and the lower the cost of it. Since the permissible levels of interference are usually known, the protection measures are chosen based on the technical and economic comparison of various protection options and analysis of the operation of the radio electronic system as a system.

Thereby, the increase of densities and electromagnetic fields levels, which influence the radio electronic system, with simultaneous vulnerability of the radio components base, ensures the relevance of the research aimed at radio electronic system proof against powerful electromagnetic intrusions.

2. Basic material

All interferences that impair the performance of radio devices are classified according to various criteria, including the distinction between internal and external, passive or active, smooth and impulse interferences [1-7]. They can also be classified according to the nature of origin: industrial, atmospheric, space.

Industrial interference is generated as a result of the operation of relatively close to electric devices, electric motors, relay-contact high-power systems, electric arc welding machines.

Cosmic interference - caused by electromagnetic radiation and processes outside the Earth's atmosphere.

Interference from radio stations - created by conventional broadcasting and special interference stations.

Internal interference - radio parts appear in the same radio device, in the normal operation of which
they interfere.

Active interference is interference caused by active natural and artificial sources of electromagnetic waves.

Atmospheric interference is caused by natural electromagnetic processes in the Earth’s atmosphere, for example, lightning discharges. This interference is also electromagnetic fields of varying frequency and intensity.

In order to evaluate systems security in case of powerful electromagnetic intrusion, experimental data at the energy level which causes damage and/or degradation of radio elements under powerful electromagnetic interference is used. With such energetic approach the energy dissipated on the element is correlated with its threshold value the one which can result in irreversible failure of the element.

Knowing equipment sensitivity characteristics, it is possible to implement the rational approach to designing an effective protection against destructive interference, penetrating through safety devices like shields, filters, etc. At that, it is necessary to choose protection methods as applied to specific equipment, taking into consideration its purpose of function. In table 1 some integrated circuits (IC) and semiconductor devices (SCD) damage levels are listed [14].

Table 1. Energy levels which lead to integrated circuits and semiconductor devices damage or degradation

| Article class | Kind of damage                                                                 | Threshold energy, J |
|---------------|--------------------------------------------------------------------------------|---------------------|
| IC            | Degradation of parameters of diodes and transistors within IC, breakdown of thin-film capacitors. Melting and burning of metal coating, contact path destruction etc. | $10^{-7}...10^{-3}$ |
| SCD           | Different kinds of breakdowns and structural damages of p-n junctions           | $5 \cdot 10^{-5}...5 \cdot 10^{-2}$ |

All methods of protection against powerful electromagnetic interferences can be nominally divided into three groups: structural, sheet-oriented and structurally-functional [14]. Let us consider thoroughly each of the existing methods aimed at increasing the resistance of radio electronic system to negative impact of powerful electromagnetic interferences.

2.1. Structural methods

The principle of structural methods consists in the application of protection elements which weren’t involved in data processing, circulating in the system. Design and creation of radio electronic system which would be noise-resistant to powerful electromagnetic interferences is rather a difficult and important problem, solution of which begins at the stage of design study. There are quite a lot of methods of structural protection of radio electronic means (REM), while the key ones are: shielding, zoning and grouping, and rational bonding.

Shielding. In order to improve hardness and protection of of radio electronic means against adverse effect of powerful electromagnetic interferences electromagnetic shields are used [14]. It should be noted that shielding is a complex process that is associated with the propagation of electromagnetic fields of radiation sources in environments with different electrophysical properties and their interaction with each other, characterized by reflection, refraction, scattering and absorption of energy of electromagnetic fields [14]. Figure 1 shows a closed case- shield radio electronic system, which is located in the electromagnetic
field of the source powerful electromagnetic interferences. The shield divides the considered space into three parts: 1 - the domain of existence of the powerful electromagnetic interferences; 2 - shield and 3 - shielded area. Each of the areas is determined by its electrophysical characteristics: \( \varepsilon \) - is the dielectric constant, \( \mu \) is the magnetic permeability and \( \sigma \) is the specific conductivity of the medium.

![Figure 1. Shield in electromagnetic field.](image)

Usually, areas 1 and 3 have the same electrophysical characteristics, which correspond to the characteristics of free space:

\[
\mu = \mu_0 = 4\pi \cdot 10^{-7} \, H / m; \quad \varepsilon = \varepsilon_0 = 8.85 \cdot 10^{-12} \, F / m; \quad \sigma = 0.
\]

The characteristics of the shield are significantly different from the above, which determines its protective properties in relation to the electromagnetic fields of powerful electromagnetic interferences.

To quantify the effectiveness of shielding, we use the following parameters: shielding factor, shielding attenuation, front change factor, and a pulse duration factor.

The shielding factor \( S \) equals the ratio of the amplitude of the electric or magnetic field strength at any point in the shielded area to the amplitude of the field strength at the same point, if the screen was absent, i.e.:

\[
S_E = E_3 / E_1; \quad S_H = H_3 / H_1.
\]

Shield attenuation - the inverse of the screening coefficient:

\[
A = 1 / S.
\]

If the acting powerful electromagnetic interference is pulsed, the shape of the pulsed field penetrating into the screen is important, which is characterized by the coefficient of change of the front and the duration of the pulse in the shielded region compared to the temporal characteristics of the acting powerful electromagnetic interference:

\[
K = \tau_3 / \tau_1.
\]

The physical fundamentals of shielding are as follows. In the process of the fall of an electromagnetic wave at the interface of two media with different electrophysical characteristics (for example: “air - metal”), the wave undergoes reflection and refraction, and in the thickness of the shield due to its conductive properties and partial absorption of electromagnetic energy. Thus, when interacting with the shield, an electromagnetic wave is reflected from its surface, partially penetrates into the wall of the shield, undergoes absorption by the shield material, repeatedly reflects from the walls of the shield and eventually partially penetrates into the shielded region.

In this case, all the above processes are accompanied by the loss of electromagnetic energy of the
wave. Thus, the total shielding efficiency is equal to the sum of the losses due to reflection, absorption and multiple reflections in the walls of thin shield.

The reflection losses at the interface between two media are associated with different values of the total characteristic resistances of these media. When a wave passes through the shield, it encounters two interfaces on its way. Although the electric and magnetic fields are reflected from each boundary differently, the cumulative effect after passing through both boundaries is the same for both fields. It should be noted that the greatest reflection (the lowest intensity of the transmitted wave) is observed for electric fields when a wave enters the shield (at the first boundary), and for magnetic fields when it leaves the shield (at the second boundary).

Since the reflection of electric fields occurs mainly on the first surface, even thin shields provide large reflection losses. The reflection loss is large for a shield made of a material with high conductivity and low magnetic permeability.

Losses due to multiple reflections in thin shields are associated with wave processes in the thickness of the shield and are mainly determined by reflection from its boundaries and absorption in the shield.

For electric fields, almost all the energy of the incident wave is reflected from the first boundary, and only a small part of it penetrates the shield. Therefore, multiple reflections inside the shield for the electric fields can be neglected.

For magnetic fields, a large part of the incident wave passes into the shield, mainly reflected, as has already been said, only at the second boundary, thus creating the prerequisites for multiple reflections inside the shield wall.

Thus, for an electric field, the main shielding mechanism is the reflection loss, and for a low-frequency magnetic field in the far-field radiation, almost all attenuation is achieved due to reflection losses, while at high frequencies the attenuation occurs mainly due to absorption, they are also decisive in shielding the magnetic fields of the near radiation zone.

However, in practice the choice of optimal shield body in terms of required protection properties results in the problem of extremely thin walls of the body which are impossible to produce, or the necessity to use very rare materials. As a result, the majority of shields are made much thicker than they need to be.

Zoning and grouping. Zoning is the identification and possible integration of areas with the same electromagnetic environment.

At the same time, additionally introduced elements and components should have a minimal effect on the functioning of radio electronic systems in normal conditions.

To limit the noise spectrum, filters, transformers and chokes are used.

To limit the pickup in amplitude in the circuits of radio electronic systems, protective dischargers are used to detect the pickup signal and remove energy in the protected systems. The operating voltage range of protective arresters lies in the range from tenths of a volt to hundreds of kilovolts.

In order to improve the hardness of radio electronic means to the influence of powerful electromagnetic interferences it is necessary that the radio electronic means elements sensitive to electromagnetic intrusion be located in the shield zones with reduced intensity level of electromagnetic fields. As there can be quite a lot of sensitive to intrusion electromagnetic fields in the radio electronic means, each of them has its sensitivity threshold, once it is exceeded the element may get out of order. They are united into separate groups by similar characteristics and assignment.

Rational bonding. When radio electronic means is designed the problems of bonding require special attention as the play an important role in the reduction of the influence of powerful electromagnetic interferences on normal functioning of radio electronic means and elimination of electrical induced noise in the nets.

2.2. Sheet-oriented methods

Sheet-oriented methods consist in task-oriented change of the structure of separate schemes and introduction of additional elements in order to weaken the influence of powerful electromagnetic interferences on normal functioning of radio electronic means. These methods provide limitations of induced noise by spectrum, limitation of induced noise by amplitude, symmetrization, application of
optical carriers etc. At that, the minimal requirements are minimal influence of the nodes, elements and systems on radio electronic means functioning under normal conditions [14].

2.3. Structurally-functional methods

Structurally functional methods consist in the change of functional principles of radio electronic means design or their separate parts and the structure of the used signals in order to improve hardness of radio electronic means to the influence of powerful electromagnetic interferences.

The main method of protection in this case is to increase the energy of the useful signals, the amplitude, duration, and the choice of carrier frequencies of the received signals taking into account the spectral characteristics of the powerful electromagnetic interferences.

Structurally-functional methods usually ensure:

- choice of the optimal signal structure;
- choice of operation algorithm;
- application of the error-correcting codes;
- choice of optimal modulation and coding system.

Having analyzed all of the abovementioned methods, it can be said that modern radio-electronic systems and complexes relate to complex control systems which have the following features:

- presence of common functioning tasks and goals for the whole system;
- the possibility of dividing the system into groups of the most closely interfacing elements, which form subsystems and have their special functioning task and goal;
- presence of hierarchical structure of subsystems connections and the hierarchy of criteria of the whole system functioning quality;
- presence of self-organization of the system;
- presence of big number of feedbacks and hardness to external and internal noises.

3. Conclusion

When designing, developing and operating the radio electronic system, it is necessary to realize complex protection measures against a negative influence of powerful electromagnetic interferences, which in turn will make it possible to ensure fail-safe functioning of the control system and guarantee operational efficiency of the system. To put it differently, each control system consisting of communications electronics equipment must have a certain hardness (functioning sustainability) under the conditions of the influence of negative powerful electromagnetic interferences.

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