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TEMPORARY AND ENERGY CRITERIA FOR PROTECTION OF RADIOELECTRONIC MEANS (AUTOMATED SYSTEMS AND TELECOMMUNICATION SYSTEMS) FROM THE DESTRUCTIVE INFLUENCE OF ELECTROMAGNETIC RADIATION

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INTRODUCTION

The results of the latest achievements in the field of protecting radio-electronic means (REM) from electromagnetic radiation (EMR) have been presented in many works, including. Many known publications have been dedicated to the traditional methods and means of protecting REM against the impact of microwave (MW) radiation[1]. At the same time, a number of works devoted to the use of radioisotope technologies, which are related to nature-like technologies in order to protect REM from the effect of powerful EMP, have appeared[2, 3, 4, 5].

The nature similarity of these technologies is associated with the formation of plasma gaseous media and solid-state materials with the subsequent usage of their trailing, reflecting and absorbing properties. An example of the closing properties of the plasma gaseous media is lightning, which represents a discharge in the air, which, as a first approximation, can be considered as an analogue of creating a highly conductive channel in the holes, slots of the case-screens so as to protect against the powerful EMR by means of guaranteed breakdown and further EMR energy drainage.

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[1] Vorobiov O., Savchenko V., Sotnikov A., Tarshin V., Kurtseitov T. Development of radioisotopic-plasmatechnology for the protection of radio electronic means from powerful electromagnetic radiation. *Eastern-European Journal of Enterprise Technologies.* 2017. Vol. 1. № 5 (85). P. 16–22. DOI: 10.15587/1729-4061.2017.91642.

[2] Iasechko M. Plasma technologies for the protection of radio electronic means from exposure to high-power electromagnetic radiations with ultra short pulse duration. Tallin, 2017. P. 18–21. DOI: 0.21303/2585-6847.2017.00480.

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Carrying out researches on the use of the protective properties of the plasma gaseous and solid media and materials requires a detailed description of the process of formation of a high-frequency channel in the holes of the REM case-screens, depending on the physical processes that occur at different stages of the breakdown development taking into account the parameters of the external EMP, as well as determining the conditions of implementation of the breakdown by time and the value of the breakdown tension.

The aim of the work is to determine the conditions and to develop the criteria for a guaranteed breakdown during the interaction with a powerful EMR with a pre-ionized air media in the REM hole.

1. Conception and principles of creation of facilities of defence of REM are from influence of powerful EMR

Presently requirements to facilities of defence or set forth approximately, or only formed during development of conceptions of defence of REM taking into account the attained and perspective levels of development of powerful generators of radio frequency and optical range of waves. As a result of insufficient worked out of conception of defence of REM not only requirements are not certain to facilities of their defence but also to descriptions of objects of defence, first of all aeroballistic objects on that these requirements depend. To such descriptions, in particular, belong:

– nomenclature of objects of defence;

– operating of objects of defence conditions;

– types and descriptions of corresponding facilities of electromagnetic influence.

The row of factors and tendencies that straight or mediated result in the decline of efficiency of application of devices and facilities of defence of REM from impulsive powerful electromagnetic influence was lately determined (EMR), to that it is possible to take the following:

– expansion of circle of solvable tasks is due to a leadingout from the capable of working state of REM;

– suddenness of application;

– reduction of requirements is to quality of information about descriptions of REM;

– expansion of types and further perfection of facilities of electromagnetic influence, that is sent to the increase of energy of EMR and reduction to the pulsewidth ($10^{-9}...10^{-18}$s);

– expansion and introduction of radio electronic equipment, that differs after principles of construction, type of element base, and also terms of application (CASS of management), system of telecommunication and connection, systems of navigation et al);

– complication of physical terms of application.

Due to these factors devices and facilities of defence of REM from EMR must provide in the superwide stripe of frequencies screening level, at that a value of energy of EMR, that will pass to the elements of REM, will be not what be more, when will take place in them effects of degradation (не більше 10^{-8} J), and removing of laser energy at that evaporation of protective material will not come true (> 0,2…2,5 J/sm^2 at $\tau_i = 10^{-9}$s).

Creation of devices and facilities of defence of REM, taking into account basic descriptions, features of application and functioning of facilities of electromagnetic influence, must be aimed at optimal combination and realization of next principles:

– absence of influence on the process of functioning of REM at cooperation with powerful EMR;

– an instantaneous reaction is on EMR (providing of necessary fast-acting is taking into account the pulsewidth of EMR);

– power independence or minimum possible energy consumptions;

– recurrence of the use;

– invariability or possible increase of gravimetric and overall descriptions of objects of defence;

– practical realization and possibility of application are both on ground and side objects.

Realization of these principles is sent to the increase of efficiency of defence of REM from powerful EMR, that is created by facilities of electromagnetic influence, radio frequency and optical range of waves, to maximum possible for the reliable functioning REM.

Researches the results of that are driven to[6, 7, 8, 9, 10, 11], showed that for protecting of REM from powerful EMR, radio frequency and optical radiation, it

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[6] Kravchenko V.I. Elektromagnitnoe oruzhie. Kharkov, 2008. 185 p.

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is needed to provide the decline of level of energy of EMR on entrances in points access in REM to maximum possible by the use of physical mechanisms, that will provide effective absorption, beating back, shorting and taking of this radiation. Thus necessarily there must be the taken into account possibilities in relation to their practical realization, and also that their application will not result in appearance of technical problems in other standards of radio electronic equipment. So, for example, under act of laser radiation there can be melting and evaporation of protective material.

Thus, for defence of side REM it is necessary to use physical mechanisms that will not lead under act of powerful EMR to destruction of facilities of defence. Therefore most expediently for protecting of side REM from a laser radiation to use the physical mechanism of his beating back.

For defence of REM of surface objects it is expedient to use first of all such physical mechanisms as absorptions and shorting of EMR with his further taking. It will provide reduction to influence of removed EMR on other REM, that are on corresponding distance.

Most expedient for defence of REM is the use of screening facilities. Realization of certain physical mechanisms is possible in corps-screens as hard plasma coverage, and in the structural opening and cable channels of introduction – as the high-leading channel artificially created under act of powerful EMR.

From the physical point of view of shorting of bit interval under act of powerful EMR there is a mechanical hasp of the weak ionized environment in the process of germination electronic of leading channel with reduced as compared to a dielectric.

Will consider marketability of these approaches from creation of materials and environments, that will provide absorption, beating back, shorting and taking of powerful EMR.

Realization of physical mechanisms of absorption of powerful EMR in plasma hard materials is possible due to providing of necessary complex dielectric and magnetic permeability of material. A dielectric or semiconductor matrix in that for providing of complex inductivity it is necessary to add the elements of radioactive substance for realization of ionising and origin of the non-equilibrium state of electronic subsystem can be used for this purpose. For providing of complex permeance it is necessary to enter the corresponding hexaferrite including. The use of elements of radioactive substance and ferrite including of corresponding sizes will provide dispersion of EMR also.

Removing of laser radiation is possible on the basis of conditioning and use of corresponding thermal physical descriptions of hard plasma material.

2. Criteria for performing breakthroughs in the holes of radio electronic means under the influence of electromagnetic radiation

Currently, a large number of scientists pay attention to the definition of energy and time criteria of various systems and subsystems of the technical nature of the application, further work takes into account the experience of these studies[12].

The formation of a high-conductivity channel is preconditioned by the different physical mechanisms of the appearance and loss of the charged particles. Depending on the stage of development of the discharge and the external conditions of impact (EMR parameters), one or the other of the mechanisms is decisive. In order to fully consider these physical mechanisms in the calculation of discharge implementation in the hole of the REM case-screens, as well as to determine the criteria of the breakdown, we will summarize the results of the research conducted and present them in the form of Fig. 1.

Let us explain the breakdown development and the energy balance at the different stage of breakdown development using the presented Figure 1.

The first stage (plasmatic) is characterized by the electron concentration $n_0 = n(Q) = Q_Д \tau_c = G \frac{\tau_c}{\Delta i}$. The distribution function of the electronic component for small holes is equilibrium, for large holes it is non-equilibrium.

The change in the electron concentration under the influence of the EMR in the second stage of the development of the conductive channel can be represented by the following equation:

$$\frac{\partial n_e}{\partial t} = \left(\nu_i - (\nu_Д + \nu_П + \nu_{Др} + \nu_p) \right) n_0 , \quad (1)$$

The realization of the condition $\nu_i \geq \nu_Д + \nu_П + \nu_{Др} + \nu_p$ means the beginning of the appearance of an avalanche, the concentration of which in the general case may be represented by the expression:

$$n_{e_{пл}}(x,t) = n(Q, E_0, x, t) \exp\left(\nu_i - (\nu_Д + \nu_П + \nu_{Др} + \nu_p) \right) t , \quad (2)$$

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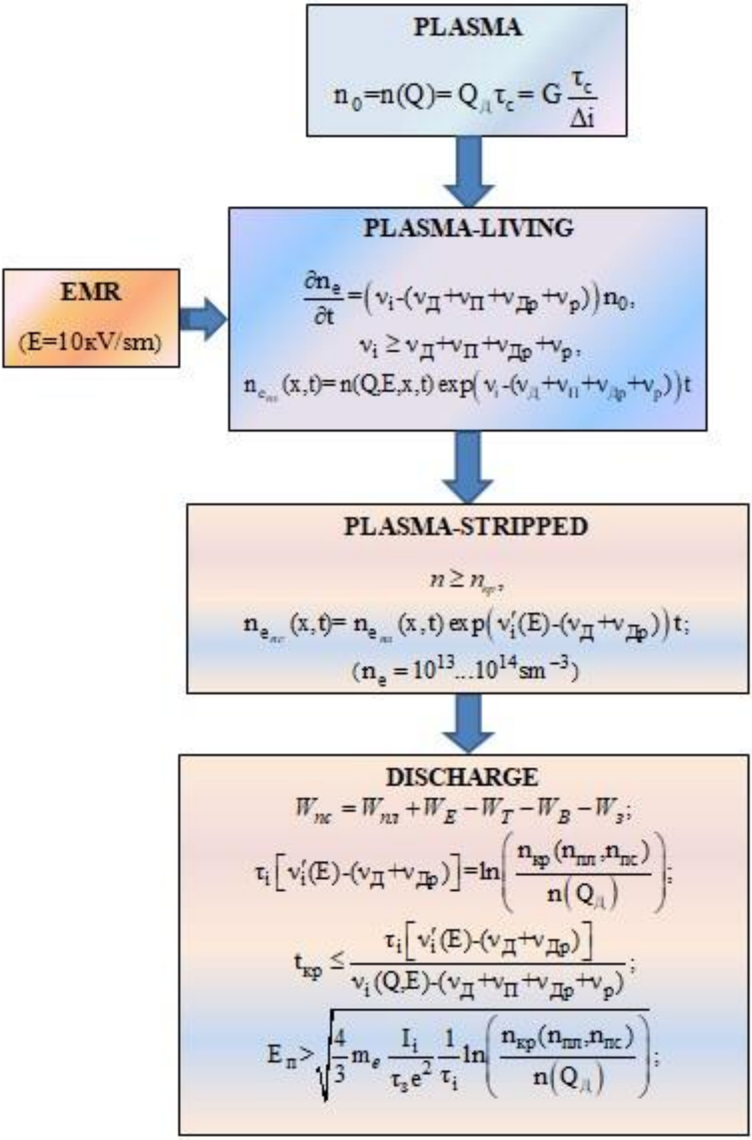

Fig. 1. The block diagram of the distribution of the electron concentration at the stages of the formation of a high-frequency channel and the breakdown of the hole of the body of the screen REM

At this stage of formation of the high-conductivity channel and the breakdown development, the external field greatly exceeds the internal field of the plasma media. But on the verge of an avalanche-streamer these fields are leveled.

According to the results of work[13, 14, 15, 16, 17], the realization of condition (1) at atmospheric air pressure is possible when $\nu_{\Pi} \approx 3 \cdot 10^{7} ... 2 \cdot 10^{6} s^{-1}$, and the recombination coefficient:

$$\alpha = (0{,}48...0{,}2)10^{-7} sm^{-3} s^{-1}.$$

Under these conditions, it is necessary that the speed of the electron production is not less than $10^{12} sm^{-3} s^{-1}$ for the existence of an electronic component of the plasma media with a concentration of $n_e = 10^{6} sm^{-3}$ at atmospheric pressure.

Ensuring of such an electron concentration is possible with the presence of an external EMR with E_0 = 10кV/sm, which is below the limit of the air breakdown, but is easily provided by the ionization source at the plasma stage.

Thus[18, 19, 20, 21, 22, 23], when using α-radioactive ionization sources, the speed of the electron production $10^{12} sm^{-3} s^{-1}$ is ensured at the activity $10^{-2} \dots 10^{-3}$ Ci/sm^3.

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In the third stage, in order to fulfill the condition $n \geq n_{кр}$ it is necessary that the frequency of the ionization exceed the loss of electrons due to their diffusion and drift, and the reduction of the influence of EMR on ionization processes due to the dissipative processes occurring in the non-equilibrium distribution of the electronic component be taken into account:

$$n_{e_{пс}}(x,t)= n_{e_{пл}}(x,t)\exp\left(\nu_i'(E)-(\nu_Д+\nu_{Др})\right)t, \qquad (3)$$

where $\nu_i'(E)$ is the ionization frequency taking into account the EMR energy losses during the interaction with non-equilibrium plasma media.

Numerical estimations $n_{e_{пс}}(x,t)$ demonstrate that at the plasma-streamer stage, the concentration of electrons in the streamer reaches the values $n_e = 10^{13}...10^{14} sm^{-3}$.

The frequencies $\nu_i'(E)$, $\nu_Д$, $\nu_{Др}$ are the function of the electron energy.

The energy balance equation at the plasma-streamer stage of the breakdown development will look as follows:

$$W_{пс} = W_{пл} + W_E - W_T - W_B - W_з, \qquad (4)$$

where $W_{пл}$ – energy of the plasma-avalanche stage; W_E – addition of energy from the external field; W_T – thermal energy losses; W_B – energy losses due to radiation; $W_з$ – energy losses due to collisions.

Given the aforesaid, the expression for the condition of the breakdown in the REM hole under the influence of EMR will look like:

$$\tau_i\left[\nu_i'(E)-(\nu_Д+\nu_{Др})\right]=\ln\left(\frac{n_{кр}(n_{пл},n_{пс})}{n\left(Q_Д\right)}\right), \qquad (5)$$

Accordingly, we shall write the expression for the time of formation of a high-frequency electronic channel:

$$t_{кр} \leq \frac{\tau_i\left[\nu_i'(E)-(\nu_Д+\nu_{Др})\right]}{\nu_i(Q,E)-(\nu_Д+\nu_П+\nu_{Др}+\nu_р)}, \qquad (6)$$

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From (5) and taking into account the electron energy under the influence of EMR – $W_e = \frac{e^2}{2m_e} \frac{E^2}{\nu_{me}^2}$ we obtain the expression for the breakdown voltage:

$$E_п > \sqrt{\frac{4}{3} m_e \frac{I_i}{\tau_з e^2} \frac{1}{\tau_i} \ln\left(\frac{n_{кр}(n_{пл}, n_{пс})}{n\left(Q_Д\right)} \right)}, \tag{7}$$

The breakdown criterion has been determined from the energy balance equation according to (4) and the particle balance (1) and (5).

The ratios (3, 5–6) include the parameter of electric voltage, which is variable due to the collective processes occurring in the ionized media of the REM hole under the influence of EMR. Thus, there is a need to identify the distribution of the electric voltage field in the interaction of EMR with the ionized air in the hole of the REM case-screen.

The process of EMP interaction with the ionized air media in the holes of the REM case-screens is described by the kinetic equation in case of large holes and quasi-equilibrium particle distribution:

$$\left.\frac{\partial f}{\partial t}\right|_з = \frac{f_0(v) - f_1\left(r,v,t\right)}{\tau} = \frac{f_0 - f_1\left(r,v,t\right)}{\tau}, \tag{8}$$

where τ is the characteristic time of collisions.

In cases of small holes and non-equilibrium distribution of the electronic component, it is advisable to use the kinetic equation of the following kind:

$$\frac{\partial f(p,t)}{\partial t} + div(\vec{j}_i) = \psi\left(p, f(p,t)\right), \tag{9}$$

The equations (8) and (9) should be supplemented with the Maxwell equations which relate the charge density ρ and stream i, as well as the electric **E** and magnetic **B** fields:

$$\begin{cases} \mathrm{rot}\mathbf{B} = \frac{4\pi}{c}\mathbf{j} + \frac{1}{c}\frac{\partial \mathbf{E}}{\partial t} \\ \mathrm{rot}\mathbf{E} = -\frac{1}{c}\frac{\partial \mathbf{B}}{\partial t} \\ \mathrm{div}\mathbf{E} = 4\pi\rho \\ \mathrm{div}\mathbf{B} = 0 \end{cases}, \tag{10}$$

The functions of distribution of the charged particles found by the solution of kinetic equations (8), (9) allow to determine all macroscopic parameters of the air media in holes, slots, cable channels of the REM case-screens, or in the waveguide antenna inputs of the receiving paths of the apparatus, and, first of all, permeability and conductivity of the ionized air media. On this basis, in order to determine the impact of EMP on REM, the system of equations (10) should be presented in the following form:

$$\begin{cases} \nabla \bar{k}\varepsilon_0 \mathbf{E}=0; \\ \nabla \mu\mu_0 \mathbf{H}=0; \\ \nabla \mathbf{E}=-\mu\mu_0 \dfrac{\partial \mathbf{H}}{\partial t}; \\ \nabla \mathbf{H}=-\bar{k}\varepsilon_0 \dfrac{\partial \mathbf{E}}{\partial t}, \end{cases} \tag{11}$$

where $\bar{k}$ is the vector wave number; ε_0, μ_0 – dielectric and magnetic permeabilities of the vacuum; μ – relative magnetic permeability.

From the system of equations (11) we obtain a wave equation with respect to the electric field strength $\mathbf{E}$:

$$\nabla \times \nabla \times \mathbf{E}=\nabla\left(\nabla, \mathbf{E}\right) - \nabla^2 \mathbf{E} = -\frac{\bar{k}\mu_0}{c^2}\frac{\partial^2 \mathbf{E}}{\partial t^2}, \tag{12}$$

A similar equation can be written with respect to the magnetic field strength $\mathbf{H}$:

$$\nabla \times \nabla \times \mathbf{H}=-\frac{\mu\varepsilon_0}{c^2}\frac{\partial^2 \mathbf{H}}{\partial t^2}, \tag{13}$$

If space dispersion is disregarded, then the expression (12) will look like:

$$\nabla^2 \mathbf{E} = \frac{\bar{k}\mu_0}{c^2}\frac{\partial^2 \mathbf{E}}{\partial t^2}, \tag{14}$$

Assuming that the spatial distribution of the electric voltage field in the interaction of EMR with the ionized air media in the hole of the REM case-screens is constant, the three-dimensional problem can be reduced to the two-dimensional one, which makes it possible to go to a system of cylindrical coordinates. Then, without taking into account the influence of the magnetic field, we will rewrite the equation (14) in the following way:

$$\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial \mathbf{E}}{\partial r}\right)+\frac{1}{r^2}\frac{\partial^2 \mathbf{E}}{\partial \theta^2}-\frac{k}{c^2}\frac{\partial^2 \mathbf{E}}{\partial t^2}=0, \tag{15}$$

The distribution of the electric voltage vector of the EMR radio pulse at the boundary of the air-ionized media of the hole will be presented as follows:

$$\mathbf{E}\left(r = a, \theta \in (-\theta;\theta)\right) = E_0 \sin(\omega_0 t) \exp\left(-\frac{t-T}{T}\right)^2 G\exp\left(-\frac{\theta_0^2}{\theta^2}\right), \quad (16)$$

where $G\exp\left(-\frac{\theta_0^2}{\theta^2}\right)$ is the EMR intensity distribution function at the plasma boundary; θ_0 is the maximum irradiation angle of the ionized air in the hole.

The solution of the equation (15) lies in the following expression:

$$E\left(r,\theta,t\right) = \frac{1}{\sqrt{2\pi}} \sum_{i=1}^{N} e^{j\omega_i t} \sum_{k=1}^{M} \left(\begin{array}{l} \frac{\cos k\theta}{2\pi} \int_{-\pi}^{\pi} E_0(\omega,\theta) \cos k\theta d\theta + \\ + \frac{\sin k\theta}{2\pi} \int_{-\pi}^{\pi} E_0(\omega,\theta) \sin k\theta d\theta \end{array} \right) \frac{L_n(r)}{L_n(m)}, \quad (17)$$

where

$$L_n(r) = Y_n\left(\frac{r\omega}{c}\right) - \frac{1}{c^2}\left(J_n\left(\frac{r\omega}{c}\right) + \frac{\left(Z_n\left(\frac{a\omega}{c}\right) + Y_n\left(\frac{a\omega}{c}\right)\right)}{N_n\left(\frac{a\omega}{c}\right)} N_n\left(\frac{r\omega}{c}\right) + Z_n\left(\frac{r\omega}{c}\right) \right),$$

N – the number of harmonics which describe the envelope function of wave packets reflected from the ionized media; M – the number of additions to the row that describe the function with the required accuracy; J_n – Bessel function of the first kind by the index n; N_n – Neumann function by the index n.

The $E_0(\omega,\theta)$ function under the integral (17) determines the boundary conditions of the problem of determining the distribution of the electric voltage field in the interaction of pulsed EMR with the ionized air media in the hole of the REM case-screen:

$$E_0(\theta,\omega) = \frac{1}{\sqrt{2\pi}} \int_0^{\tau} e^{-j\omega t} E_{max} \exp\left(-\frac{t^2}{2a^2}\right) \sin(\omega t) \exp\left(-\frac{\theta_0^2}{\theta^2}\right) dt.a, \quad (18)$$

The $Z_n\left(\frac{r\omega}{c}\right)$ function is determined by solving the non-uniform Bessel equation for $L_n\left(r/c\right)$, which is determined by the plasma frequency parameter, in which the concentration of charged particles is considering losses.

The expression (18) is a model for the distribution of the electric voltage field in the interaction of pulse EMR with the ionized air media in the hole of the REM case-screen.

CONCLUSIONS

One of perspective directions of defence of REM from powerful EMR there is application of plasma technologies. One of realization of this direction is considered for protecting of REM from powerful EMR, that influences through the structural opening and cable channels of introduction. Analytical expressions over are brought for realization of mathematical design of cooperation of impulsive EMR with a homogeneous plasma environment. The terms of defence are certain depending on the parameters of impulse of EMR, plasma environment and pressure of air, there is defence at that.

SUMMARY

The conditions of realization of the guaranteed breakdown in the REM holes with the interaction of the powerful EMR with the pre-ionized air media have been determined. The criteria have been developed and analytical expressions for the time of formation of a high-frequency electronic channel and the breakdown voltage have been obtained. The equation for describing the dynamics of the spatial-temporal distribution of the microwave pulse voltage in the ionized air media of the hole of the REM case-screen have been obtained, taking into account kinetic processes in the ionized air media, in particular taking into account the impact of charged particle losses on the formation of a high-frequency channel.

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