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Protection of Board Radioelectronic Equipment from the Destructive Powerful Electromagnetic Radiation with the use of Natural Technologies

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ABSTRACT

The composition of airborne equipment is analyzed. It Indicates the need to solve the problem of protecting the board radio electronic means from the effects of powerful electromagnetic radiation.The article uses natural technologies to protect structural openings and board radio electronic means inputs from the effects of electromagnetic radiation. Board radio electronic means protection device was developed. Analytical conditions for board radio electronic means protection have been determined. Discharge criteria for guaranteeing board radio electronic means protection are proposed. It takes into account the powerful electromagnetic radiation parameters and the state of the ionized medium in the discharge point.

Key words: board radio electronic means, electromagnetic radiation, ultrashort pulse duration, plasma (natural) protection technologies, gaseous plasma media.

1. INTRODUCTION

Analysis of well-known methods, methods and devices of defence of board radio electronic means (REM) from a powerful electromagnetic radiation (EMR) showed that they in the development substantially fell behind from methods and facilities of generuting powerful impulsive EMR, development of that is sent to the further increase powers of radiation and reduction of pulsewidth. Development, creation and use of generators with a radiation power of the order of and more than 1 GW with pulse duration of 10^{-9} to 10^{-18} seconds necessitates

the further development of methods and devices for the protection of radio electronic means. This is due to the possibility of both accidental and deliberate (as a result of terrorist acts) use of such generators, which can lead to the board REM disruption at considerable distances. At the same time, the threat of board REM serviceability disruption is usually created when electromagnetic radiation interacts with antennas, communication lines, conductors and radioelements of equipment. Figure 1 shows an example of the composition of on-board radio electronic means of aircraft [1,6, 13-17].

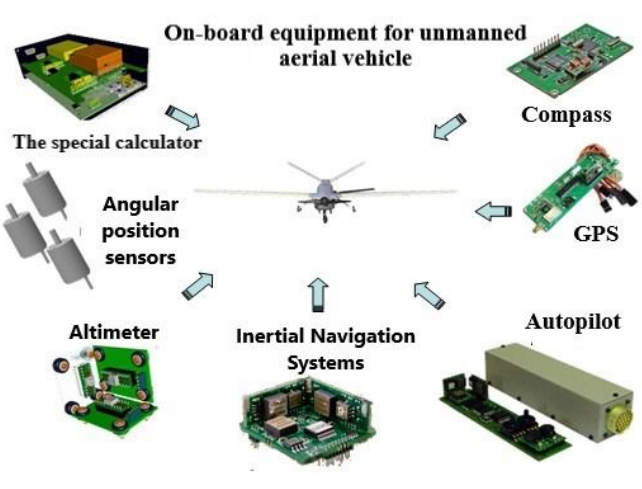

Figure 1: An example of the composition of on-board radio electronic means of aircraft

The most vulnerable to the EMR influence are the board REM elements directly connected to the antenna output, to the cables and conductors. In addition to these elements, the cables themselves are exposed to impulse voltages, which in certain cases can damage their insulation and cause a short circuit between its cores and the sheath. The most dangerous in terms of its impact on radio electronic equipment (REE) is a powerful EMR of the ultrashort pulse duration (UPD) [20, 21].

Proceeding from this, the problem of ensuring the durability and reliability of modern board REM to the impact of powerful EMR of ultrashort pulse duration acquires a pronounced systemic character.

REE features, as a protection object, determine the requirements for the applied protective devices, which must:

have high speed;

not influence the characteristics of the protected radio facilities;

have stability of characteristics in a wide range of temperatures under the action of damaging EMR factors;

have ability to quickly restore its electrical strength in conditions of multiple exposure to EMR;

have overall dimensions and weight smaller than the overall dimensions and mass of the protected equipment.

1.1 Problem analysis

1. 1.2 Conception and principles of creation of facilities of defence of board REM of aircraft 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 board 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 board 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 board 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 board REM;

suddenness of application;

reduction of requirements is to quality of information about descriptions of board 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 board 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 board 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 board 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 board 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 board 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 board REM.

Researches the results, showed that for protecting of board REM from powerful EMR, radio frequency and optical radiation, it is needed to provide the decline of level of energy of EMR on entrances in points access in board 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 board 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 board REM from a laser radiation to use the physical mechanism of his beating back.

For defence of board board 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 board REM, that are on corresponding distance.

Most expedient for defence of board 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. MAIN MATERIAL

2.1 Application of natural technologies is for creation of defence of board REM of aircraft from influence of powerful EMR

In works of authors it offers to use natural technologies that in most degrees answer descriptions of facilities of defence.

The use of natural (plasma) technologies introduces in facilities of defence the row of new properties in comparing to ordinary facilities. Most essential from them is an instantaneous reaction of the state of electronic subsystem, and, accordingly, change of electric physical properties of hard and ionized air environment, that determine beatings back, absorptive and locking properties of facilities of defence, under act of powerful impulsive EMR, capacity on the draught of all life cycle of REM, ability to maintain impulsive overstrains.

One of more simple realization of method of defence of board REM from powerful EMR, that influences through the structural opening and cable channels of introduction, causing is on the internal surface of wall of opening of radioisotopic tape that is a weak radioactive source. The use of ionising source as radioisotopic tape results in an origin in the air interval of the weak ionized plasma ($n_{e0}=10^3…10^5 sm^{-3}$), what on the properties in case of the use for defence of aerial waveguide channel will not result in the origin of heterogeneity in co-ordinate space and, accordingly, to distortion of useful signal. In addition, radioisotopic tape taking into account a small thickness also will not result in the increase of overall descriptions of object of defence.
Under act of powerful EMR the concentration of the charged parts of the weak ionized plasma will grow, that will result in the origin of the artificially created high-leading channel, that an electric hasp of air interval is between the walls of opening or between a cable and opening walls [19].

Development of discharge for creation of high leading channel, it is determined by many factors. The parameters of EMR (pulse width of EMR, frequency of pulse-repetition and their energy), and also physical processes, that take place on the different stages of discharge, and determine the terms of his origin, behave to them. In other words creation of high-leading channel is determined by the process of cooperation of powerful EMR with a gas-plasma environment.

Thus, as a result of creation of high leading channel shorting or beating back and taking of impulsive powerful EMR will take place from opening of screens-corps.

Will consider more in detail creation of high-leading channel on the example of application of below-cutoff waveguide. With the aim of observance of requirements in relation to providing of necessary overall descriptions of corps-screens of board REM it is suggested on the internal surface of waveguide attachment to inflict a layer from α – radioactive substance as thin tape (fig 2). As a result in waveguide attachment inwardly or in space between internal a wall attachment and appears a cable weak an air environment is ionized.

Such going near realization of means of defence allows substantially to decrease thickness of waveguide attachment at hard requirements to overall descriptions, to increase due to the non-equilibrium state of electronic subsystem of absorption of EMR, in case of action of powerful EMR provide it complete taking due to creation of discharge in the preliminary ionized air environment. Distance between the midwalls of waveguide attachment at defence directly of opening must be not more than 7,6 sm (two lengths of tracks α – parts), and during connection of cables and explorers through opening not more than 3,8 sm [6].

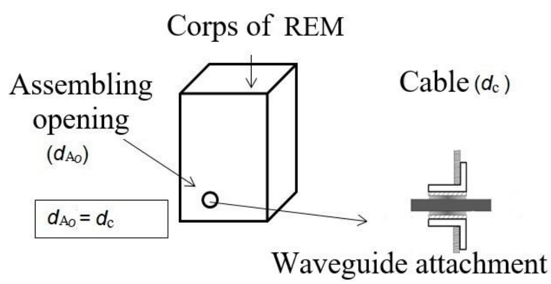

Figure-2: Device of board REM of aircraft defence

Work of an offer device consists in the following.

EMR falls on a layer from α – radioactive substance that creates non-equilibrium weak an air environment is ionized. Between the midwalls of waveguide attachment the non-equilibrium weak is created an air environment that is characterized the sizes of one order in relation to actual and imaginary part of inductivity is ionized. As a result there is a considerable increase of absorption of EMR. In case of powerful EMR in non-equilibrium weak the ionized air environment there is discharge and taking of energy through the corps of board REM, that is earthed. Waveguide attachment acts part corps for causing of radioisotopic tape and does not more determine protective properties of below-cutoff waveguide, that allows substantially to decrease the thickness of walls of attachment.

Thus, the use of layer of radioisotopic tape results in reduction of overall sizes to the corps-screen, increase of absorption of EMR, and in case of action of powerful EMR to the hasp and taking of energy through the corps of board REM, that is earthed.

Practical realization of an offer device of defence needs determination of terms of origin of discharge, in particular hasp tension, size of activity of source of the previous ionising and time for that a high leading channel will be created. It stipulates the necessity of research of electric physical properties of the ionized air environment at distribution in it powerful impulsive EMR.

In the first approaching will consider that a plasma environment that arises up between the walls of waveguide attachment under act of powerful EMR is homogeneous and terms are executed for realization of discharge of Townsend $n_e \geq n_{кр}$, $n_{кр} = m_e\omega^2 / 4\pi e^2$ – critical concentration of electrons;

Coming from it, for description of terms of discharge it is enough to apply the system of equalizations, that includes:

1) equalization is for description of distribution of EMR:

$$\frac{\partial^2 \bar{E}}{\partial z^2} - \frac{1}{c^2}\frac{\partial^2 \bar{E}}{\partial t^2} = \frac{4\pi}{c^2}\left[\left(n_{e0}+n_e\right)\frac{\partial \bar{V}_e}{\partial t} + \bar{V}_e\frac{\partial n_e}{\partial t}\right], \qquad (1)$$

where n_e – change of concentration of electrons;

V_e – oscillometric speed of electrons;
E – tension of electric-field;

2) equalization that describes the change of concentration:

$$\frac{\partial n_e}{\partial t} + div\bar{j} = (\nu_i - \nu_n)n_e, \qquad (2)$$

where ν_n – frequency of losses of electrons (of loss determined by the processes of recombination, adhesion and diffusion).

Frequencies ν_i and ν_n are the functions of energy of electrons.

Will consider in future, that ionising grows in time on an exponential law, the amount of electrons increases in time in accordance with correlation:

$$n_e = n_{e_0} e^{(\nu_{me} - \nu_n)t};$$

3) equalization of balance of energy:

$$\frac{\partial}{\partial t}(n_e\varepsilon) = n_e Q - d\nu_n(\varepsilon - \varepsilon_0) - \nu_i\varpi_i n_e - n_e\varpi_d, \qquad (3)$$

where ε_0 – middle energy of heavy parts.

The first constituent in right part of expression (3) describes losses energies of impulse, that take place during the warming-up of electrons that is determined by expression:

$$Q = \frac{(eE)^2}{2m_e(\omega + \nu_{me})^2}\,, \tag{4}$$

where ν_{me} – frequency of collision of electrons is from neutrals;

m_e – mass to the electron.

The second and third constituents take into account losses as a result of different collisions with heavy parts, energy of that ε_0, d – part of energy that is lost by an electron at a resilient collision with heavy parts (a coefficient of passed to energy is from electrons to neutrals), ϖ_i – ionising potential. The last constituent allows to describe the losses of energy as a result of thermodiffusion [7, 9, 11].

Possibly, that the action of impulse and frequency of filling satisfy correlation $\omega\tau >> 1$. Then it is possible to take advantage of method slowly variable amplitude, in accordance with that the field of impulse can be presented in a kind:

$$E = E(z,t)exp(-iwt + ikz), \tag{5}$$

where $E(z,t)$ – slowly variable amplitude.

Will enter dimensionless to the change:

$$f = \frac{E(z,t)}{E_n};\; n = \frac{\tau_u\omega}{2}\frac{n_e}{n_{\kappa p}};\; W_i = \frac{\varepsilon_{cp}}{\varpi_i};\; z \to \frac{z}{c\tau_u};\; t \to \alpha_B\tau_u\,,$$

where τ_u – pulsewidth;

W_i – ionising energy.

At tension $E = E_n$, energy of fluctuating motion $\frac{mv^2}{2}$ equals ionising energy W_i, $n_{\kappa p}$ – critical closeness of plasma that answers working frequency ω, a_B – digital time dimensionless factor, that allows to change a time scale factor, ε_{cp} – middle energy to the electron.

Taking into account the done suppositions the simplified system of equalizations (1 – 3, 5), what describes passing of impulse in a homogeneous gas environment taking into account the warming-up of electrons and ionising in the field of impulse, looks like:

$$\frac{\partial f}{\partial z} + \frac{1}{\alpha_B}\frac{\partial f}{\partial t} = i\frac{1 + iV_e/\omega}{1 + iV_e^2/\omega^2}nf;$$

$$\frac{1}{\alpha_B}\frac{\partial n}{\partial t} = \tau_0 p\left\{\begin{aligned}&\left(\frac{\nu_i - \nu_a - \alpha_p n_{\kappa p} n}{\nu_{me}}\right)n - \\ &-\frac{1}{c^2\tau_u^2\nu_{me_i}}\frac{\partial^2}{\partial z^2}(D_a n)\end{aligned}\right\}; \tag{6}$$

$$\frac{1}{\alpha_B}\frac{\partial W}{\partial t} = 5\tau_0 p\left\{f^2 - \delta\left(\begin{aligned}&W - W_0 - \frac{\nu_i}{\nu_{me}} - \\ &-\frac{W\partial n/\partial t}{5\tau_0(N_0 + n)} - \\ &-\frac{W_i}{c^2\tau_u^2\nu_{me}(N_0 + n)}\times \\ &\times\frac{\partial}{\partial z}\left(\frac{D_{T_e} n\partial W}{W_i\partial z}\right)\end{aligned}\right)\right\},$$

where $N_0 = \frac{\tau_u\omega}{2}\frac{n_{e_0}}{n_{\kappa p}}$;

$D_{T_e} = e_{cp}/m_e\nu_{me}$ – coefficient of thermodiffusion;
$W_0 = \varepsilon_0/W_i$;
$\tau_0 = \tau_u 10^9$ c;
ν_a – frequency of adhesion;
V_e – speed to the electron.

The system of equalizations (6) presents system of non-stationary equalizations at partial derivative functions with nonlinear coefficients.

In initial moment on plasma, that is characterized the concentration of electrons, that makes a few percents from a value $c\tau_u$, and initial energy of electrons is fates of percents from energy of ionising W_i, the impulse of EMR influences with a profile Gauss:

$$E(Z_0) = Aexp\left[\frac{(Z - Z_0)^2}{c^2\tau_u^2}\right], \tag{7}$$

The terms of discharge will get from equalization to continuity for electrons:

$$\frac{\partial n}{\partial t} = \nu_{me}n_e - \nabla\Gamma\,, \tag{8}$$

where n_e – concentration of electrons;

ν_{me} – speed of creation of electrons is on one electron that is difference between speed of ionising and speed of adhesion;

Γ – a closeness of electronic current of losses is in the consequence of diffusion on walls, that is shown in electrons in 1 s on unit of surface.

With the increase of electric-field n_{me} increases, while derivative at times $\partial n/\partial t$ will not become positive. It is envisaged that discharge takes place in that moment when derivative $\partial n/\partial t$ goes across through a zero. The offensive of discharge testifies that the electric field in this moment attained a characteristic size that is determined by equalization:

$$\nu_{me} n_e - \nabla \Gamma = 0 . \quad (9)$$

If to enter a size $y = -\tilde{N} D n_e$,

where D – coefficient of diffusion of electrons, then the terms of discharge can be presented in a kind:

$$\tilde{N}^2 y + x_i E^2 y = 0 , \quad (11)$$

E – root-mean-square of electric-field;

$x_i = n / DE^2$ – ionising coefficient.

It is necessary for the origin of discharge, that speed of creation of electrons in the process of ionising was more speed of loss of electrons in the consequence of diffusion. In case of the homogeneous field between parallel plates there is a gradient of aggressive tension E_n, length of interval d and to pressure of gas p bound by next correlation:

$$(pd)^2 = \frac{\pi^3 k T_e}{e(E_n / p)(\alpha_T / p)} , \quad (12)$$

where T_e – temperature of electrons;
a_T – the first coefficient of ionising is after Townsend;
k – permanent Boltzmann.

If the condition of hasp consists in that the number of electrons some number must exceed in an interval $n_{\kappa p}$, then, that discharge was it is necessary, that a next condition was executed:

$$(\nu_{me} - \nu_n) \geq \frac{1}{\tau_u} ln\left(\frac{n_{\kappa p}}{n_{e0}}\right) . \quad (13)$$

Due to that the last condition is writtenin in a logarithmic form, for corresponding calculations it is not needed high exactness in case if $n_{\kappa p}$ large. Reliable value $n_{\kappa p}$ it can be to the order 10^{13} sm^{-3}. Size ν_{me} has the same essence, that and ionising coefficient a_T. In an eider, where absent adhesion is, where the basic process of loss of electrons is diffusion, number ν_n insignificant and it is possible to assume that during a few first microseconds of loss of electrons are absent. Therefore aggressive tension is determined by a pulsewidth, and discharge takes place at implementation of correlation:

$$n_{me} = \frac{1}{\tau_u} ln\left(\frac{n_{\kappa p}}{n_{e_0}}\right) . \quad (14)$$

Middle energy to the electron at a free run in the field E, what changes with frequency ω, equals:

$$\varepsilon_{cp} = \frac{e^2}{2m_e} \frac{E^2}{(\nu_{me} + \omega)^2} .$$

Possibly, that for time between collisions an electron collects energy ε_{cp}, while it will not attain a size ϖ_i to potential of ionising of gas. At a collision, there is ionising, an electron loses all his energy, and a process begins first.

On the basis of such model of ionising process it is possible to get expression for ν_{me}, a next condition swims out for the size of the field E_n in the moment of discharge:

$$E_n^2 > \frac{4\varpi_i}{e/m} \frac{\omega^2 + \frac{1}{3}\nu_{me}^2}{\nu_{me}} \frac{1}{\tau_u} \ln\left(\frac{n_{\kappa p}}{n_{e0}}\right) . \quad (15)$$

From expression (15) evidently, that the increase of initial concentration of electrons in an interval will result in the decline of tension of electric-field. In addition, the increase of initial concentration of electrons results in less dependence of tension of electric-field on pressure of air [8, 10, 12].

Thus, undertaken studies confirm expediency of the use of plasma technologies for creation of impermeable in relation to powerful EMR screens.

3. CONCLUSION

One of perspective directions of defence of board REM from powerful EMR there is application of plasma technologies. One of realization of this direction is considered for protecting of board 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.

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