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The Investigation of the Impulse Evolution of the Radio-Frequency and Optical Radiation During the Interaction With the Solid-State Plasma Media On Radioisotope and Hexaferrite Inclusions

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ABSTRACT

The article deals with the topicality of the question of development of fundamentally new means of protection of radio-electronic equipment based on the use of natural (plasma) technologies against the destructive effect of radio-frequency and optical (laser) radiation.

The impact of the solid-state plasma media on the evolution of the impulse of radio-frequency and optical radiation has been studied and investigated.

The impact of the solid-state plasma media on the passage of narrowband radio-frequency radiation and broadband impulse optical radiation has been estimated.

Key words: radio electronic means, electromagnetic radiation, ultrashort pulse duration, control system, plasma protection technologies, gaseous plasma media.

1. INTRODUCTION

The powerful optical radiation generators that can lead to unintentional destructive effects and the destruction of radio electronic means (equipment) are a promising area of development and creation worldwide.

The most widespread in application and most effective methods of protection against optical (laser) radiation are the ablation protection and the constructive thermal insulation protection.

The usage of known methods of protection of electronic means against the destructive effects of optical radiation is not always possible for a number of reasons, such as the impossibility of repeated usage, weight and dimensional characteristics (inadmissibility of usage on light flying objects), the lack of the ability to protect antenna feeder paths, installation openings, cable glands of the REM case.

It is possible to improve the effectiveness of REM protection against the destructive effects through the use of natural (plasma) technologies, the use of psychical mechanisms of which will provide the effective absorption, reflection and removal of optical (laser) radiation.

The essence of such technologies lies in the usage of natural plasma technologies which to the greatest extent satisfy the set of requirements for the means of protection [1,2, 5, 13-18, 22-30, 32].

Therefore, the studies related to the protection of REM against the destructive effects of EMR, namely optical (laser) radiation, are quite relevant and require studying and addressing the question of the impact of the solid-state plasma media on the evolution of radio-frequency (RF) and optical radiation (OR) are preconditioned by two factors:

– the impulse electromagnetic radiation (EMR) has an ultrashort (from 10^{-9} to 10^{-18} s) pulse duration which can be considered as a set of narrowband groups, each of which is propagating at its group velocity. As a result, a temporary burst of impulse will take place, which in the conditions of shielding of radio electronic means (REM) can be considered as positive;

– the existing methods of analysis, such as the method of slowly varying amplitude, become approximate in the study of femtosecond and attosecond pulsed radiation, which is preconditioned by the need to take into account higher approximations of the variance theory.

As the solid-state plasma medium is proposed to be used for the protection against the destructive effects of radio-frequency EMR, as well as for OR, thus, the aim of the article is to estimate the impact of the solid-state plasma medium on the passage of narrowband radio-frequency radiation and broadband pulsed optical radiation.

2. MAIN MATERIAL

2.1 The estimation of the impact of the solid-state plasma medium on the evolution of a radio-frequency pulse

The estimation of the impact of a solid-state plasma medium on the evolution of the RF radiation pulse will be conducted in accordance with the results of the papers [7, 10, 11, 31], given that:

1. The solid-state plasma medium is dispersive, nonlinear, and absorbent;

2. The radio-frequency radiation is narrowband with the carrier frequency $\omega_н$, which will be considered as a wave packet.

For RF radiation, the width of the spectrum $\Delta\omega$ is determined according to the following expression [31]:

$$\Delta\omega=\frac{1}{\tau_i}=\omega_н . \quad (1)$$

Let us suppose that at the boundary of a solid-state plasma medium, there operates an electric field $E(t,z=0)=E_0(t)$, which, when interacting with the medium, has a frequency spectrum, which, given the attenuation, is described according to the expression [31]:

$$S(\omega)=\frac{1}{2p}\int_{-\infty}^{\infty}E_0(t)\exp(j\omega t)dt. \quad (2)$$

Assuming that the spectral components propagate in the medium independently of one another, the solution of the wave equation according to [10] will have the following form:

$$E(z,t)=\int_{-\infty}^{\infty}S(\omega)\exp\left\{-j\left[\omega t-k(\omega)z\right]\right\}d\omega . \quad (3)$$

Taking into account (3), the solution on the boundary across the field will be as follows:

$$E(z,t)=\frac{1}{2p}\int_{-\infty}^{\infty}\int_{-\infty}^{\infty}E_0(t')\exp\left\{-j\left[\omega(t-t')-k(\omega)z\right]\right\}d\omega dt'. \quad (4)$$

Then, for the wave packet, decomposing the dependence of the wave number $k(\omega)$ into a Taylor series, the expression describing the field wll have the following form [10]:

$$E(z,t)=\frac{1}{2\pi}\int_{-\infty}^{\infty}E_0(t')dt'\int\exp\left\{-j\left[(t-t')-\frac{dk}{d\omega}z\right](\omega-\omega_0)+\right.$$
$$\left.+\frac{1}{2}jz\frac{d^2k}{d\omega^2}(\omega-\omega_0)^2+...\right\}d\omega\exp\left[j(k_0z-\omega_0t)\right]. \quad (5)$$

In our case, to calculate the ratio of growth increments, it suffices to restrict to the use of the first two terms of the decomposition:

$$E(z,t)=E_0(t')(t-k'(\omega_0)z)\exp\left[-j(k(\omega_0)z-\omega_0t)\right]. \quad (4.27)$$

According to (6), the wave packet will propagate at the group speed:

$$v_{гр}=\left(\frac{dk}{d\omega}\right)_{\omega 0}^{-1} .$$

Since the group velocity makes sense when the propagation medium is characterized by low absorption, then the expression (6) indicates the deformation of the impulse associated with its shape.

The RF radiation is high-frequency which propagates in the first approximation without distortions.

Taking into account the quadratic term in (5), an imaginary diffusion coefficient appears, resulting in a change in the amplitude profile of the wave packet during the dispersion propagation of the wave pocket.

For the Gaussian impulse $E_0(t)=\frac{1}{\tau_i}\exp\left(-\frac{t^2}{2\tau_i^2}\right)$, an expression describing a field can be written in the following form [11]:

$$E(z,t)=E_0(\omega)\frac{1}{\sqrt{\tau_i^2-jk''(\omega_0)z}}\times$$
$$\times\exp\left(-\frac{2(t-k'(\omega_0)z)^2}{(\tau_i^2-jk''(\omega_0)z)}\right)\exp(-jk(\omega_0)z-\omega_0t) . \quad (7)$$

It can be seen that the impulse duration increases with distance by the value according to the expression [10, 31]:

$$\tau_i(z) = \sqrt{\tau_i^2 + \left(\frac{(k''(\omega_0)\,z)}{\tau_i^2}\right)^2} . \quad (8)$$

2.2 The estimation of the impact of the solid-state plasma medium on the evolution of an optical radiation impulse

The OR, unlike radio frequency, is broadband, which studies the interaction with the dispersion medium by the Green's function method [10, 31].

Let us assume that the solid-state plasma material is affected by the initial field $E(0,t)=E_0(t)\exp(-j\omega_o t)$.

To describe the field, we will use the space-time function $g(z,t)$ with initial conditions $g(0,t)=\delta(t)$ of the following kind:

$$g(z,t)=\frac{1}{2\pi}\int_{-\infty}^{\infty}\exp(-j(\omega t-k(\omega)z)) \quad (9)$$

Then we will write the expression for the field in the following form:

$$E(z,t)=\int_{-\infty}^{\infty} g(z,(t-t_0))E_0(t_0)dt_0 . \quad (10)$$

Let us note that at $t<\frac{z}{c}$ the function $g(z,t)=0$, and at $t>\frac{z}{c}$ the function $g(z,t)\neq 0$.

Let us consider the second case.

Without reducing the generality of the considerations, the impact of the plasma material on the evolution of the EMR pulse will be investigated with the use of non-contact plasma.

This approach makes it easier to conduct the research. It does not take into account only the mechanism of energy absorption of the impulse that will affect the decrease of its amplitude.

For such a plasma medium, the wave vector module noted through the plasma frequency will be determined according to the following expression:

$$k_0(\omega)=\frac{\sqrt{\omega^2-\omega_p^2}}{c} . \quad (11)$$

To account for the impact of higher wave number $k(\omega)$ approximations on the impulse evolution according to the Taylor series, we will present the first five terms of the decomposition, which we will later use in the implementation of numerical simulation. The generalized wave number $k(\omega)$ approximations above have the following form:

$$k_n(\omega)=\left.\frac{d^n k(\omega)}{d\omega^n}\right|_{\omega=\omega_0} .$$

Then we will write the first five approximations in the following form:

$$k_1(\omega)=\frac{1}{c}\frac{\omega_0}{\sqrt{\omega_0^2-\omega_p^2}} ; \quad k_2(\omega)=-\frac{1}{c}\frac{\omega_p^2}{\sqrt{\left(\omega_0^2-\omega_p^2\right)^3}} ;$$

$$k_3(\omega)=\frac{3}{c}\frac{\omega_0^2\cdot\omega_p^2}{\sqrt{\left(\omega_0^2-\omega_p^2\right)^5}} ; \quad (12)$$

$$k_4(\omega)=-\frac{3\omega_p^2}{c}\frac{(4\omega_0^2+\omega_p^2)}{\sqrt{\left(\omega_0^2-\omega_p^2\right)^7}} ; k_5(\omega)=\frac{\omega_p^2}{c}\frac{(60\omega_0^2+45\omega_p^2)}{\sqrt{\left(\omega_0^2-\omega_p^2\right)^9}} .$$

Accordingly, the expression for the field (10) taking into account the dispersion of the material, can be represented in the following form:

$$E(z,t)=E_0(\omega t-kz)-\frac{\omega_p z}{c}\int_{\frac{z}{c}}^{\infty}\frac{J_1\left(\omega_p\sqrt{\tau^2-\left(\frac{z}{c}\right)^2}\right)}{\sqrt{\tau^2-\left(\frac{z}{c}\right)^2}}E_0(t-\tau)d\tau , \quad (13)$$

where $J_1\left(\omega_p\sqrt{\tau^2-\left(\frac{z}{c}\right)^2}\right)$ is the Bessel function.

The analysis of ratios (7) and (11) indicates the evolution of the pulsed radiation during its interaction with the dispersion plasma material, which consists in the temporal propagation of the impulse.

The results of numerical simulation of the evolution of pulsed radiation during its interaction with the dispersion plasma material are shown in fig. 1.

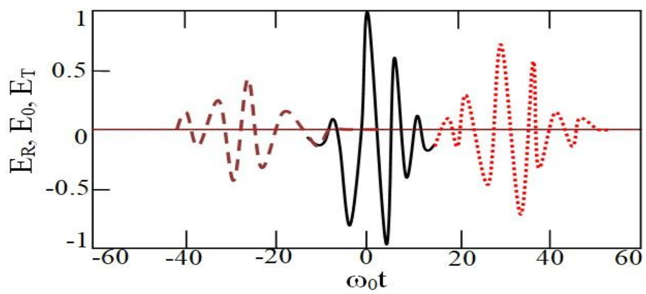

Figure 1: The results of numerical simulation of the evolution of the impact of the dispersion properties of a solid-state plasma medium on pulsed radiation bursting

Fig. 1 shows that the interaction of the pulsed radiation with the solid-state plasma medium brings its decomposition, and this applies both to the impulse that has passed into the depth of the material E_T, as well as E_R reflected from it.

5. CONCLUSION

The impact of the solid-state plasma on the passage of narrowband radio-frequency radiation and broadband pulsed optical radiation has been estimated.

It has been shown that without using the mechanism of decay instability at the thickness of the protective material in the order of units of millimeters, it is impossible to carry out the shielding of REM, since a slight increase in the impulse length does not significantly affect the penetrating power of pulsed radiation.

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