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Diffraction of a monopolar electromagnetic pulse on a slit

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Abstract. The two-dimensional problem of diffraction of a monopolar electromagnetic pulse on a slit is considered by the methods of a computational experiment. The structure of the diffraction field is analyzed for various ratios of the slit width and the spatial pulse length. It is shown that if the slit width significantly exceeds the length of the incident monopolar pulse, then, regardless of its polarization, the diffraction field is bipolar.
Keywords: monopolar electromagnetic pulse, diffraction, computer simulation.

1. Introduction

At present, the problem of generating ultrashort pulses (USPs) in various ranges of electromagnetic radiation is of particular interest. In particular, a review of recent publications devoted to monopolar and quasi-monopolar pulses in the optical range, in which methods for the generation, propagation, and interaction of monopolar light with classical and quantum systems are discussed, was carried out in [1]. In the same work, a classification of UPSs based on the shape of the dependence of the electric field component on time was proposed. It is proposed to call such pulses monopolar, in which the values of the specified component in the considered time interval have the same sign.

Research is also underway on the possibility of generating monopolar electromagnetic pulses (MEMP) in the microwave range. As an example, we can cite the work [2], which presents the results of theoretical and experimental work related to the emission of a quasi-monopolar pulse with a duration of ~0.5 ns. Other possible ways of generating MEMP, which are suitable for the microwave range, are described in [3, 4].

Separately, there is the problem of MEMP transformation, namely, changing the direction of its propagation, focusing, etc. The problems of non-stationary MEMP diffraction related to this problem for some cases of two-dimensional objects were considered in [5–7]. In these works, in particular, it was concluded that the space-time structure of the electromagnetic field scattered by an obstacle depends on the polarization of the incident pulse.

Since real focusing systems have an aperture of a finite size, the problem of the influence of the edges of such systems on the dynamics of the MEMP field seems to be important. The simplest object with a finite aperture on which the main features of the MEMI diffraction field can be revealed is a slit in an infinite ideally conducting screen.

The purpose of this work was to study the spatiotemporal configuration of the field formed as a result of MEMP scattering on such an object.

2. Formulation of the problem

Let a two-dimensional region G, coinciding with the XOY plane of the Cartesian coordinate system, contain an ideally conducting screen with a slit of a given width. Through area G in the positive direction of the axis X, perpendicular to the screen, MEMP propagates, having a flat front. The space-time profile of the pulse coincides with that considered in [5, 7], namely, the MEMP field first increases according to a quadratic law, then, after reaching the maximum value, it decreases exponentially. Let us consider two cases that differ from each other by the polarization of the pulse incident on the object:

1) TE-polarized MEMP (the electric field is parallel to the Z axis, the magnetic field vector lies in the XOY plane);

2) *TM*-polarized MEMP ($\boldsymbol{H}^{(i)} = \{0, 0, H_z^{(i)}\}$, $\boldsymbol{E}^{(i)} = \{0, 0, E_z^{(i)}\}$).

Thus, the electrical component of the MEMI for both cases can be written as follows:

$$A(x,y,t) = \begin{cases} 0, & \dfrac{t-(x-x_0)}{c} < 0 \\ \alpha_0\left(t-(x-x_0)/c\right)^2 \exp\left(-\beta(t-(x-x_0)/c)\right), & \dfrac{t-(x-x_0)}{c} \geq 0 \end{cases}, \tag{1}$$

where α_0 is the MEMP amplitude, x_0 is the position of the pulse front at $t = 0$, β is the coefficient that determines the pulse duration, c is the speed of light in vacuum, $A(x,y,t) = E_z^{(i)}(x,y,t)$ for *TE*-polarized MEMP and $A(x,y,t) = E_z^{(i)}(x,y,t)$ for the case of *TM*-polarization.

In what follows, the total field will be represented as a superposition of the MEMP field and the diffraction field:

$$\mathbf{H} = \mathbf{H}^{(i)} + \mathbf{H}^{(s)},\ \mathbf{E} = \mathbf{E}^{(i)} + \mathbf{E}^{(s)}$$

We will investigate the dynamics of the electromagnetic field using the system of Maxwell's equations. The component-by-component representation of this system for the case of *TE*-polarization has the following form:

$$\frac{\partial E_z(x,y,t)}{\partial t} = \frac{1}{\varepsilon_0}\left\{\frac{\partial H_y(x,y,t)}{\partial x} - \frac{\partial H_x(x,y,t)}{\partial y}\right\}, \tag{2.1}$$

$$\frac{\partial H_x(x,y,t)}{\partial t} = -\frac{1}{\mu_0}\frac{\partial E_z(x,y,t)}{\partial y}, \tag{2.2}$$

$$\frac{\partial H_y(x,y,t)}{\partial t} = \frac{1}{\mu_0}\frac{\partial E_z(x,y,t)}{\partial x} \tag{2.3}$$

For *TM*-polarization, the system of equations is written for other field components:

$$\frac{\partial H_z(x,y,t)}{\partial t} = -\frac{1}{\mu_0}\left\{\frac{\partial E_y(x,y,t)}{\partial x} - \frac{\partial E_x(x,y,t)}{\partial y}\right\}, \tag{3.1}$$

$$\frac{\partial E_x(x,y,t)}{\partial t} = \frac{1}{\varepsilon_0}\frac{\partial H_z(x,y,t)}{\partial y}, \tag{3.2}$$

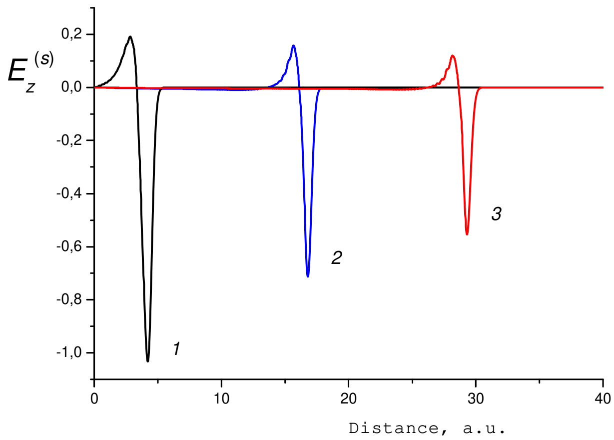
$$\frac{\partial E_y(x,y,t)}{\partial t} = -\frac{1}{\varepsilon_0}\frac{\partial H_z(x,y,t)}{\partial x} \tag{3.3}$$

The solution of the systems of equations (2) and (3) with the corresponding initial and boundary conditions will be carried out by the numerical method, which is based on the finite-difference approach.

3. Simulation results

In the computational experiments performed, the slot width L varied from 3 to $12c\tau$, where τ is the duration of the incident pulse, which was determined from the level of 0.5 of the field amplitude. The center of the slit coincided with the origin of the coordinate system. In all the cases considered, the scenario of the formation of the diffraction field coincided qualitatively. Namely, the incident MEMP excited two cylindrical waves at the edges of the screen, the interference of which formed a pattern of nonstationary diffraction. Note that the field of cylindrical waves excited in this way had a bipolar form.

Fig.1. shows the curves corresponding to the spatial distribution of the field $E_z^{(s)}(x)$ (*TE*-polarization, Fig.1a) and $H_z^{(s)}(x)$ (*TM*-polarization, Fig.1b), at fixed times. Slit width $L = 5c\tau$. In view of the fact that the waves propagate in free space outside the scattering object, one can speak of an unambiguous relationship between the temporal and spatial dependences of the diffraction field.



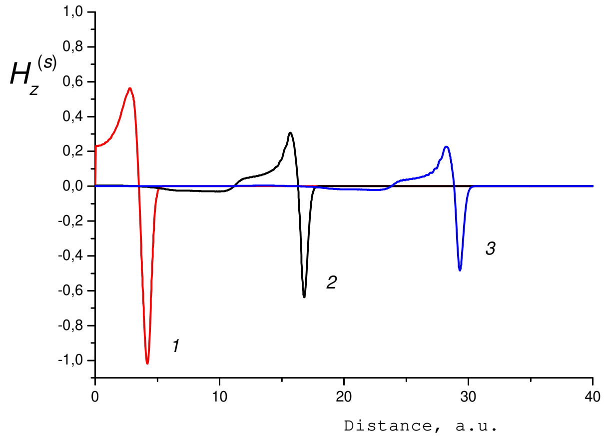


Fig.1. Diffraction field on the axis of the system at different times (curves *1*, *2*, *3*).
Case of *TE*- (*a*) and *TM*- (*b*) MEMP polarization.

For the case of *TE*-polarization, the time dependence of these waves was close in its form to the time derivative of the MEMP field. A more complex field dynamics took place for the case of *TM*-polarization of the MEMP. If the initial time dependence of the field was also proportional to the time derivative of the incident pulse, then an additional field jump was observed in the next time interval. The value of the product of the speed of light and the time duration of this interval corresponds to the width of the slit. Thus, it can be argued that the indicated field jump is formed due to the reflection of a cylindrical wave from the end of the slit opposite to the excitation point.

4. Conclusion

As follows from the results obtained, the field scattered by the inhomogeneity, regardless of the MEMP polarization, is not monopolar. Cylindrical waves emitted as a result of MEMP diffraction from the edges of a perfectly conducting screen, both for *TE*- and *TM*-polarizations, turn out to be bipolar.

Thus, the following statement can be made: the use of focusing systems with a finite aperture and sharp boundaries significantly change the structure of the MEMP electromagnetic field and it ceases to be monopolar.

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