# CONVERSION OF A FLAT FRONT OF A UNIPOLAR RADIATION PULSE INTO A CYLINDRICAL ONE

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**Abstract.** The problem of nonstationary diffraction of a monopolar TM-polarized electromagnetic pulse with a flat front on a thin slit in a perfectly conducting screen is considered. Using computational experiment methods, it has been shown that if the slit width is much smaller than the spatial length of the pulse, then a field is formed behind the screen in the form of a cylindrical monopolar pulse, i.e. there is a transformation of the shape of the incident field front without changing its character (monopolarity).

**Keywords:** *monopolar electromagnetic pulse, non-stationary diffraction, front shape transformation*

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## INTRODUCTION

The problem of generation of ultra-short electromagnetic pulses has been topical for many years. The ways of its solution are constantly developing and depend, in particular, on the frequency range.

The problem of generating electromagnetic pulses whose duration is a fraction of the oscillation period (see, e.g., [1]) should be emphasized. In the literature, such pulses are called uni- or monopolar (MEMI) [2]. A detailed review of works by Russian authors on the subject under consideration is presented in [3].

Theoretical and experimental studies of MEMI are of interest from both general physical and applied points of view. If we speak about fundamental problems of MEMI generation, we should mention the work [4], in which it was proved in several ways that it is generally impossible to create a unipolar pulse in three-dimensional space by a set of spatially bounded sources. Consequently, as noted, in particular, in [3], when considering the MEMI, one should specify the spatial domain and the time interval on which the MEMI exists. For example, in [5], one of the methods of generation in the microwave range of a pair of MEMI of opposite sign is considered. A spatially short electric current is chosen as a source, the time dependence of which has the form of a trapezoid. It is shown that the spatial-temporal separation of the pair pulses is determined by the duration of the time interval on which the current is constant.

A separate task is to transform the characteristics of MEMI, such as changing the direction of propagation, their focusing, etc., which would not lead to the destruction of the main property of MEMI: monopolarity.

Thus, in [6], a theoretical analysis of the propagation of a unipolar precursor generated as a result of multiphoton ionization in an electro-optic crystal induced by an ultrashort laser pulse is given. In the same work it is pointed out that as the above electromagnetic formation propagates, it loses the properties of monopolarity, which once again confirms the fact that it is possible to speak about the existence of MEMI only when considering some limited region of space in a limited time interval. The results of the experimental observation of the unipolar precursor are given in [7].

Taking into account these spatial and temporal constraints, we considered the problems of MEMI diffraction on the simplest two-dimensional objects: infinite cylinder, ribbon, etc. [8-10]. It was pointed out a significant difference in the diffraction field dynamics for different polarizations of the electric field *E of* the incident MEMI. If the vector *E* was directed parallel to the object, the diffraction field was close to the unipolar form in most cases considered by computational experiment methods. If the vector *E* lay in the cross-sectional plane of the object, the diffraction field was sign-variable.

Note that in these works the transverse linear dimensions of the objects significantly exceeded the spatial length of the incident pulse $L_{\mathrm{imp}}$, defined as the product of its temporal duration by the speed of light. Proceeding from the mechanism of the alternating field formation (due to the excitation of cylindrical waves at the edges of objects) proposed in these works, the following assumption can be made for the problem of diffraction on a slit of MEMI having a flat front. If the width of the slit is much smaller than the spatial length of the incident pulse, we should expect the formation of the diffraction field, the structure of which will be close to monopolar. The shape of the diffraction field front may be cylindrical.

## PROBLEM STATEMENT

To verify this assumption, consider the following problem.

Let a monopolar electromagnetic pulse *1* with a flat front propagates in the positive direction of the *x-axis* in a two-dimensional region *G* (Fig. *1*), whose electrodynamic characteristics coincide with those of free space. The pulse has one component of the electric field different from zero, which at the left boundary of *G* depends on time *t as* follows:

$$E_y(t)=\begin{cases}0, & t<0\\ E_0\sin^2\left(\dfrac{\pi}{2}\dfrac{t}{\tau_1}\right), & 0\le t<\tau_1\\ E_0\exp\left(-\left(\dfrac{t-\tau_1}{\tau_2}\right)^2\right), & t\ge\tau_1\end{cases}, \tag{1}$$

where $E_0$ is the amplitude of the electric field strength, $\tau_1$ is the duration of the leading edge of the pulse (the time for which the field reaches the maximum value from zero), $\tau_2$ is the parameter determining the duration of the trailing edge of the pulse. Note that $L_{имп} \approx c\,(\tau_1+\tau_2)$ , where *c* is the speed of light in vacuum.

The region contains an infinite in the *y-axis* direction perfectly conducting screen *2* with a slit of width *d*. The screen has a finite thickness *h* (along the *x-axis* of the chosen coordinate system). The edges of the screen forming the slit have a rounding, the radius of which is equal to *h/2*.

Let us find the dynamics of the electromagnetic field in the region *G*. For this purpose, let us use the system of Maxwell's differential equations in the space-time representation [11]. Let us consider such a polarization of the field that only one magnetic component (*TM-polarization*) is different from zero along the *z-axis* perpendicular to the location plane of *G*. Taking into account that in free space the dielectric ($\varepsilon$) and magnetic ($\mu$) permeabilities are equal to unity, the component-by-component formulation of the equations is as follows:

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

$$\frac{\partial E_x(x,y,t)}{\partial t} = \frac{1}{\varepsilon_0}\frac{\partial H_z(x,y,t)}{\partial y}, \qquad (2)$$

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

where $\varepsilon_0$ and $\mu_0$ are the electric and magnetic constants, respectively.

Suppose that up to the moment $t = 0$ there is no electromagnetic field in *G*. At $t >$ 0 the electric field at the left boundary of *G* corresponds to (1). There is no reflection of electromagnetic waves from the bottom, top, and right boundaries of *G*. The boundary conditions on the screen surface correspond to the boundary conditions on a perfectly conducting surface.

To solve the system of Maxwell's equations with the specified initial and boundary conditions, we use a numerical method based on finite-difference approximation of partial derivatives in spatial coordinates and time [12]. The absence of reflection of the wave field from the boundaries of *G* will be ensured by the introduction of a perfectly matched layer [13].

MODELING RESULTS

Numerical modeling of the considered system was performed with the following fixed parameters. The length of the region *G* (*x* direction) was 700 cm, the width (*y* direction) 400 cm. The screen, the thickness of which was 5 cm, was located at a distance of 352.5 cm from the left boundary of *G*. The radius of rounding of the edges of the screen was 2.5 cm. The incident electromagnetic pulse had a unit amplitude $H_0 =$ 1, $\tau_1 = 5 \cdot 10^{-10}$ s, $\tau_2 = 3 \cdot 10^{-10}$ s. Its spatial length $L_{imp} =$ 24 cm.

The variable parameter in the modeling was the slit width *d*, which corresponded to the distance between the rounded edges of the screen. The dependences of the value of the magnetic component of the field on the longitudinal coordinate on the line passing through the middle of the slit at a fixed moment of time, as well as the spatial distribution of this field in the right part of the region *G* (behind the screen) were used as controlled quantities.

The conducted modeling of the field dynamics showed that at the ratio $L_{imp}/ d > 5$ a monopolar cylindrical pulse is formed behind the screen, the amplitude of which decreases with the increase of the mentioned ratio.

Characteristic dependences of the diffraction field are shown in Fig. 2. which were obtained for $L_{imp}/ d \sim 5$. For convenience of consideration, the origin of the *x-axis* is combined with the right border of the screen. The zero of the vertical coordinate coincides with the center of the slit. The moment of time $t = 0$ corresponds to the appearance of MEMI on the left boundary *G*.

Fig. 2a shows the dependences of the $H_z$ distribution on the longitudinal coordinate at the moments of time $t = 132$, 148, 165, 181, and 198 ns (curves *1*, *2*, *3*, *4*, and *5*, respectively). The maximum values of the generated MEMI decrease with distance from the slit $\sim 1/\sqrt{r}$ , which corresponds to the law of decreasing amplitude of a cylindrical wave with distance to its source. The amplitude of the diffraction field $H_0^{диф}$ , as well as the magnitude of the observed kink at the trailing edge of the pulse (indicated in Fig. 2a by the arrow) decreases with increasing ratio $L_{imp}/ d$. For $L_{imp}/ d = 5$, the value is $H_0^{диф} / H_0 \approx 0.25$ . Thus, when the slit width tends to zero, the diffraction field profile will tend to the incident pulse profile, but at the same time $H_0^{диф}$ will also be vanishingly small.

Fig. 2b shows the isolines of the magnetic component of the diffraction field plotted at time $t$= 135 ns. Note that near the line $y$= 0, a region of maximum values is observed, and most of the isolines have the form of half-circles, which corresponds to the phase surfaces of a cylindrical wave, i.e., it can be stated that the plane front of the initial MEMI was transformed into a cylindrical one.

## CONCLUSION

Thus, based on the results of computational experiments, we can consider that the diffraction field of MEMI with a flat front on an ideally conducting screen with a slit whose width satisfies the condition $L_{imp}/d \gg 1$, has the form of a monopolar pulse with a cylindrical front. This property can be used in experimental works on the effect of MEMI on artificial and natural objects.

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FIGURE CAPTIONS

**Fig. 1.** Toward a problem statement.

**Fig. 2.** Dependence of the diffraction magnetic field on the longitudinal coordinate (a) and its spatial distribution (b).

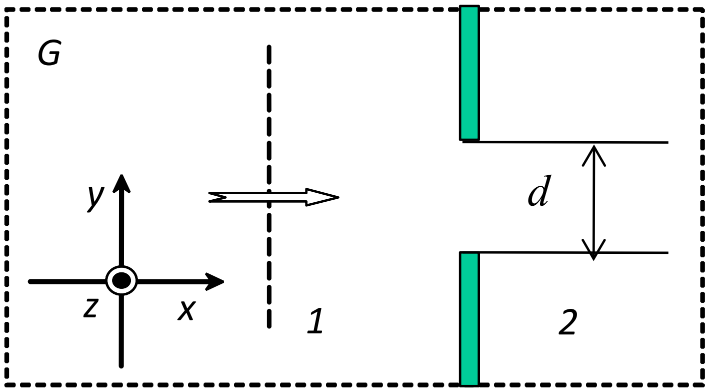
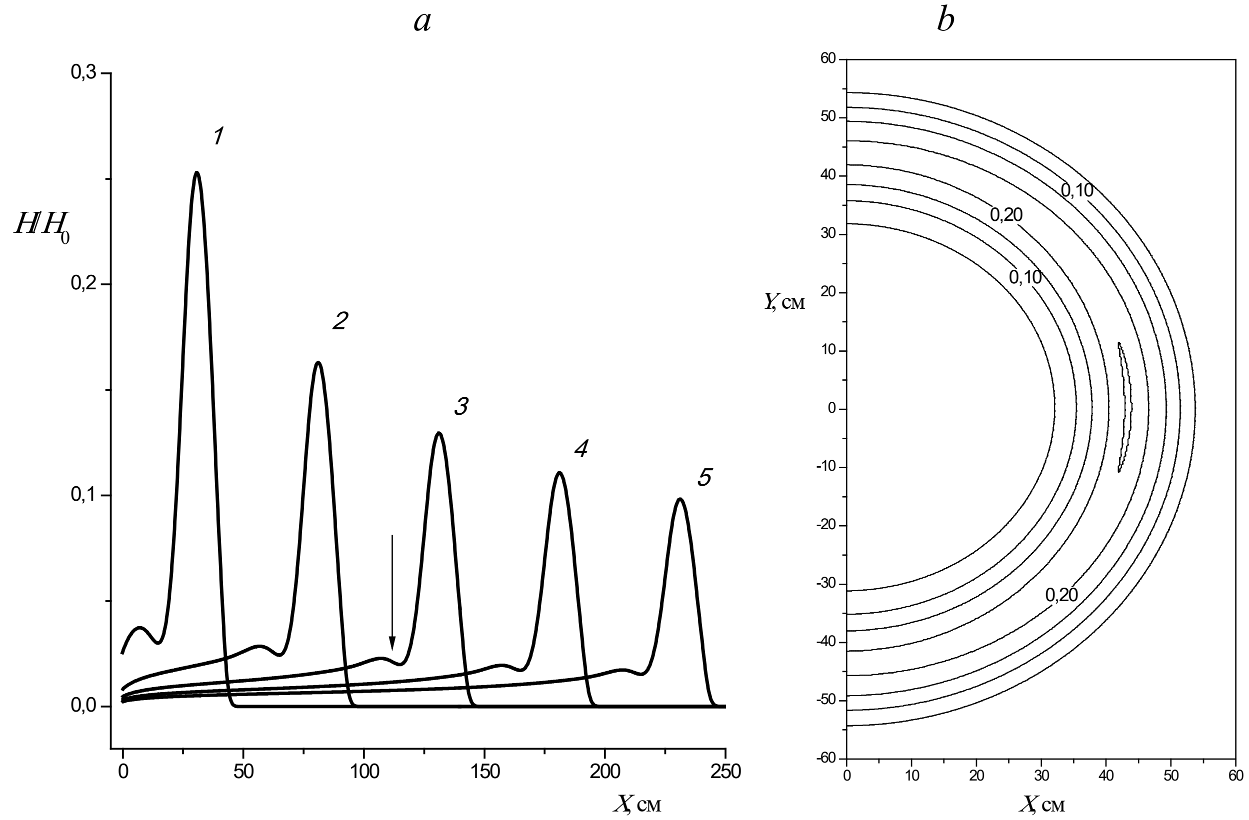



Fig. 1.


a
b
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H/H0
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2
3
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50
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200
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X, см
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Y, см
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X, см

Fig. 2.