AN EXCITATION OF THE LINEAR ANTENNA BY THE RELATIVISTIC CHARGE IN THE CIRCULAR WAVEGUIDE

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Abstract

Excitation of a linear impedance antenna is considered in a unlimited circular waveguide. The antenna is located in the waveguide axis and is excited by the relativistic point charge scattered at the antenna end-wall. The electric current distribution and the charge linear density distribution along the antenna are calculated. The delta-shaped representation of a current on one of the antenna ends at the initial instant of time is given. The Green's function of an unlimited circular waveguide, and also the direct and inverse Fourier transform in time domain are used.

Keywords: Transition radiation, UWB antenna, a relativistic charge, a circular waveguide, the integral equation.

1. INTRODUCTION

A promising type of the ultrowideband radiation is the transition radiation [1] which arises when a uniformly moving charged particle crosses the interface of two media. The transition radiation finds an application in the microwave electronics [2, p.19], is used in accelerating technique devices.

Applications of the transition radiation in the antenna and waveguide technics are considered in [3] and [4] and some aspects of the transition radiation are studied in [5].

In [6] it is demonstrated that by scattering the relativistic point charge on a thin perfectly conducting disk both the transition and diffraction radiations are formed. The radiation of the linear antenna excited by the relativistic electronic beam scattering on the antenna end-wall is investigated in the experimental work [7]. The current induced by the point relativistic charge running to the end-wall of the linear impedance antenna in the unlimited space, is calculated in [8]

The current and the linear density of the charge, excited in the linear impedance antenna of a longitudinal orientation in the circular waveguide, as a result of a relativistic point charge scattering on one of the antenna ends, are calculated in the present publication.

2. ANALYTICAL EXPRESSIONS

The linear impedance antenna having the length L and the radius a is located on the axis of a circular waveguide having the radius R. The antenna is excited by the point charge Q moving along the axis of the with waveguide with a constant velocity v. The volume current density of a free charge scattered on the target is

$$\vec{j}_Q(t,r') = \frac{Q}{\rho'}\delta(\rho')\delta(\varphi')\delta(z'-vt)v\theta(t)\vec{z}_0, \qquad (1)$$

where ρ', φ', z' are the cylindrical system coordinates, $\rho'=0$, $\varphi'=0$, $z'=vt$ are the charge coordinates, and $\theta(t)$ is the Heaviside function.

According to [9, p.29] we have

$$\begin{aligned} & div_r\left(\frac{\partial \varepsilon\varepsilon_0 \vec{E}(t,r)}{\partial t} + \vec{j}_Q(t,r)\right) = \\ & div_r(\vec{j}_p(t,r) + \vec{j}_Q(t,r)) = 0 \end{aligned}, \qquad (2)$$

where $\vec{j}_p(t,r) = \dfrac{\partial \varepsilon\varepsilon_0 \vec{E}(t,r)}{\partial t}$ is the current polarization density, and $\vec{j}_Q(t,r)$ is the free-charge current density. Integration (1) using transverse coordinates, with taking into account (2), gives a boundary condition for the current at the antenna end

$$\frac{\partial J(t,l=0)}{\partial l} = \frac{1}{\rho}Q\delta(t), \qquad (3)$$

where ρ is the antenna edge radius, l is the longitudinal coordinate in the antenna coordinate system, and $J(t,l)$ is, mainly, the polarization current along the impedance antenna. Taking into account the direct Fourier transformation in the time domain for (3), we reduce the solution of the nonhomogeneous differential equation on the segment determined by the formula (1) in [10] to the solution of a nonhomogeneous differential equation with a small parameter.

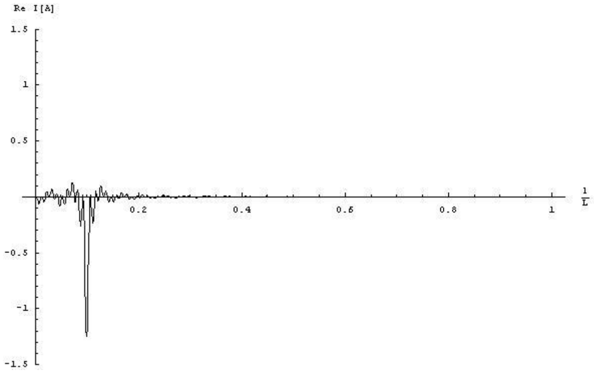

Fig. 1. Current along the linear antenna t =0.1*10^-9s; L = 0.3 m; Q =-10^-11Q; v = 0.94c; R = 0.25 m; $a = 0.01m$; $\rho = 0.001m$

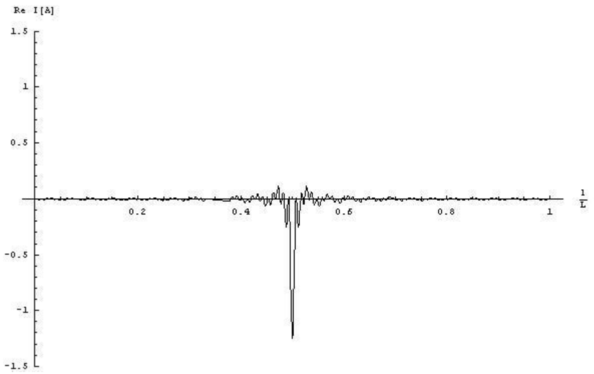

Fig. 2. Current along the linear antenna t= 0.5*10^-9s; L = 0.3 m; Q =-10^-11Q; v = 0.94c; R = 0.25 m; $a = 0.01m$; $\rho = 0.001m$

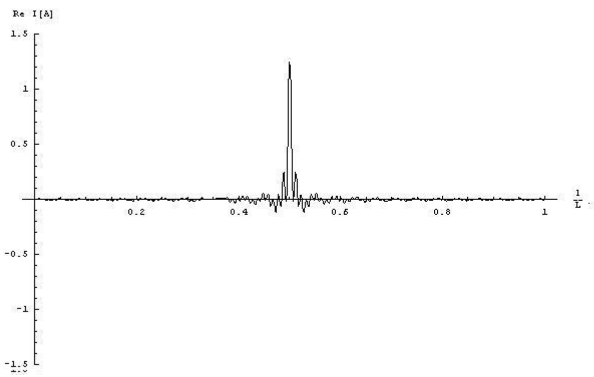

Fig. 3. Current along the linear antenna t =1.5*10^-9s; L = 0.3 m; Q =-10^-11Q; v = 0.94c; R = 0.25 m; $a = 0.01m$; $\rho = 0.001m$

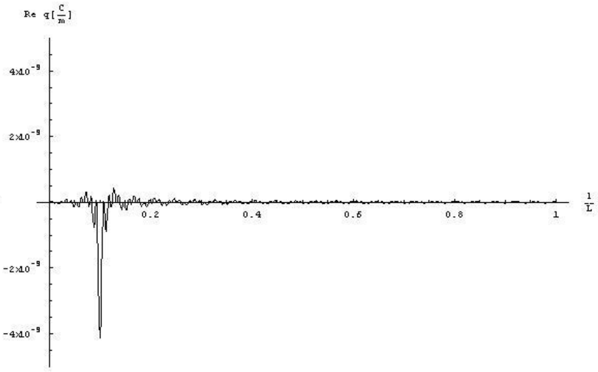

Fig. 4. Density of a charge along the linear antenna t= 0.1*10^-9s; L = 0.3 m; Q =-10^-11Q; v = 0.94c; R =0.25 m; $a = 0.01m$; $\rho = 0.001m$

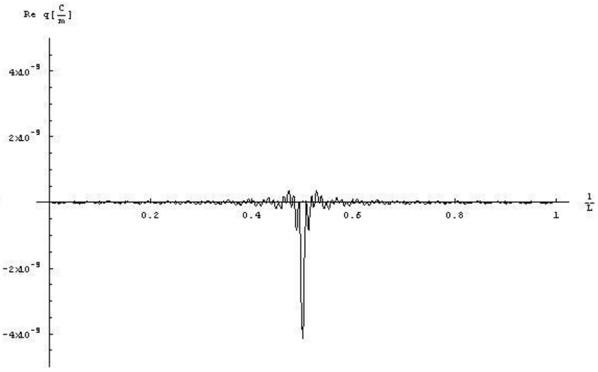

Fig. 5. Density of a charge along the linear antenna t= 0.5*10^-9s; L = 0.3 m; Q =-10^-11Q; v = 0.94c; R =0.25 m; $a = 0.01m$; $\rho = 0.001m$

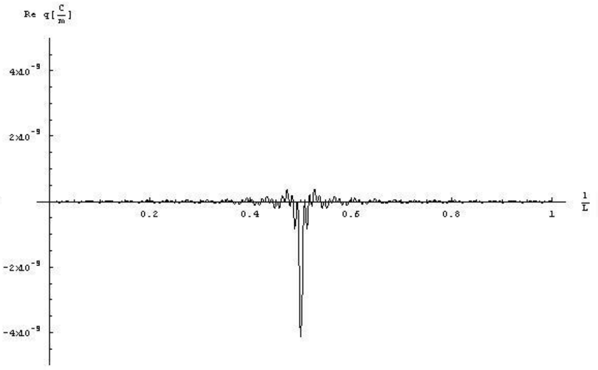

Fig. 6. Density of a charge along the linear antenna t= 1.5*10^-9s; L = 0.3 m; Q =-10^-11Q; v = 0.94c; R =0.25 m; $a = 0.01m$; $\rho = 0.001m$

$$\frac{d^2 J(\omega,l)}{dl^2} + k^2 J(\omega,l) = \alpha\{i\omega\varepsilon_0 E_0(\omega,l) + F_0[l,J] + \tilde{F}_0[l,J] + F[l,J] + (-1)i\omega\varepsilon_0 \dot{Z}J\} \quad (4)$$

with inhomogeneous boundary conditions

$$\partial J(\omega, l=0)/\partial l = (1/\rho)Q, \quad (5)$$

$$J(\omega, l=L) = 0 \quad (6)$$

in the space-frequency representation.

Applying the inverse Fourier transformation for the solution of problem (4) - (6) and carrying out the integration in the complex plane $\dot{\omega}$, we obtain the electric current force in the form of the spectrum of eigen frequencies for the impedance antenna.

$$J(t,l) = \sum_{p=-\infty}^{+\infty} [ie^{-i\omega_p t}/((L/\sqrt{\varepsilon_0\mu_0})\cos\dot{\tilde{k}}(\omega_p)L + \alpha\frac{d}{d\omega}W(\dot{\tilde{k}}(\omega_p)L))]\{\ Q\sin\dot{\tilde{k}}(\omega_p)(L-l) + \alpha Q[\cos\dot{\tilde{k}}(\omega_p)(L-l)\int_0^L G_{E_{ll'}}(k(\omega_p);L;l')\times \sin\dot{\tilde{k}}(\omega_p)(L-l')dl' - \cos\dot{\tilde{k}}(\omega_p)l\int_0^L G_{E_{ll'}}(k(\omega_p);L;l')\times \sin\dot{\tilde{k}}(\omega_p)(L-l')dl'] - \alpha(i/Z_0)\int_0^L E_0(l')\sin\dot{\tilde{k}}(\omega_p)(L-l')dl'\}, \quad (7)$$

where ω_p there are roots of the dispersive equation

$$\sin\dot{\tilde{k}}(\omega_p)L + \alpha W(\dot{\tilde{k}}(\omega_p)L) = 0, \quad (8)$$

$W(\dot{\tilde{k}}(\omega_p)L)$ there is

$$W(\dot{\tilde{k}}(\omega_p)L) = \int_0^L [G_{E_{ll'}}(k(\omega_p);L;l')\cos\dot{\tilde{k}}(\omega_p)L - G_{E_{ll'}}(k(\omega_p);0;l')]\sin\dot{\tilde{k}}(\omega_p)(L-l')dl',$$

and other symbols are given in [10].

3. Numerical results

The charge current distribution and the charge linear density distribution along the linear impedance antenna were calculated according to (7) and (7) with the use of the continuity equation for p=200. The charge current and the charge density are presented in the plots of Fig.1-3 and Fig.4-6 respectively.

To values of time t=0.1 ns; t=0.5 ns; t=1.5 ns corresponding are Fig.1,4; Fig.2,5; Fig.3,6 respectively, the point charge being contacting with the antenna end-wall during the zero moment of time. The waveguide radius was taken equal to R=0.25 m, for the case when the wave front, reflected from the waveguide walls, did not achieve the antenna.

4. Conclusions

The problem of point charge scattering on the linear impedance antenna is solved as a diffraction problem when an extraneous field source in the form of a point current source is on the scattering body surface.

The mode of self-excited oscillations makes an essential contribution into the current distribution along the antenna. The mode of forced oscillations related, in particular, with the extraneous electric field intensity, determines the current components being the first-order infinitesimal values.

The current pulse, reflected from the antenna end-wall, changes its sign i.e. at the antenna end the radiation intensity should be maximum.

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