Theoretical Study of Transient Cherenkov Radiation from Periodic Resonance Medium Excited at the Superluminal Velocity

R.M. Arkhipov¹, I. Babushkin²

¹Weierstrass Institute, Berlin, Germany,

²Institute of Mathematics, Humboldt University of Berlin, Berlin

M.V. Arkhipov³, Yu. A. Tolmachev³

³Faculty of Physics, Saint-Petersburg State University,
Saint-Petersburg, Russia

Abstract— we consider an optical response of one-dimensional string made of dipoles with a periodically varying density excited by a laser pulse moving along the string at the superluminal velocity. We demonstrate that the Cherenkov radiation arising in such system is rather unusual, possessing both transient and resonant character. Our analysis indicates that in addition to the resonance frequency of the medium another Doppler-like frequency appears in the radiation spectrum.

Keywords— Cherenkov radiation, superluminal motions, ultra-short pulse

The problem of superluminal motion and attracts attention of various researchers for rather long time [1]. In optics it is well-known that spots of light can propagate at the superluminal velocity, as it was considered by I.M. Frank, B.M. Bolotovskii and V.L. Ginzburg [2]. Among them there are spots of light formed by the rotating searchlight (or pulsar in astrophysics) at a fairly remote screen or the illumination of a flat screen with plane wave, where the intersection of the pulse and the screen moves along the screen at the velocity $V = c/\sin \beta > c$ (β is the angle of wave incidence) [2], and an intersection of two interfering laser beams which propagates at the velocity $V = c/\cos \alpha > c$ (2α being the angle between two interfering waves) [2-4].

In the present work, we consider in details the Cherenkov-type radiation in the case of a 1D string formed of dipoles (or two-level atoms) with a spatially-periodic modulated number density with period Λ_z . This system is excited at the superluminal velocity at the point of intersection of the string with a moving spot of light.

In our study we assume that the medium consists of identical dipole oscillators (or two-level atoms) with resonance frequency ω_0 and damping constant γ arranged along a string length Z_m , with a periodic distribution of the oscillator density. We consider the spectral and temporal dynamics of the Cherenkov radiation, which occurs in such system in the transient regime. We demonstrate the appearance of a new Doppler-like frequency in the spectrum of the transient Cherenkov radiation. In the case of linear topology the frequency Ω_1 depends on the angle of the observation φ and is given by [3-4]:

$$\Omega_1 = 2\pi \frac{V/\Lambda_z}{|\frac{V}{c} \cos \varphi - 1|}. \quad (1)$$

Finally we demonstrate that the new frequency arises also in the case of the circular geometry of the oscillator string when medium oscillators periodically distributed over the circle.

In the case when the signal has large enough amplitude, the response of the dipoles becomes nonlinear our analysis provided in this case indicates that in the strong-signal regime, when the nonlinearity in the string response becomes significant, the new frequency may even significantly overcome the resonant one.

The behavior described there can find its application, for instance, to shape the broad spectra and short pulses in desired way using rather compact setup. Also the frequency of new component can be used to determine the velocity of motion of superluminal excitations in a resonant medium. Another possible application is a generation of the new frequency in the linear and nonlinear resonant medium and for determination of a spatial structure of scattering system (for example crystal illuminated by ultra-short X-ray pulse) by the spectrum of the scattered wave.

ACKNOWLEDGMENT

R.M. Arkhipov would like to acknowledge the support of EU FP7 ITN PROPHET (Grant No. 264687).

REFERENCES

- [1] G.B. Malykin, E.A. Romanets, "Superluminal Motion (Review)," Optics and Spectroscopy, vol. 112(6), 920-934, (2012).
- [2] B.M. Bolotovskii, V.L. Ginzburg, "The Vavilov-Cerenkov Effect and the Doppler Effect in the Motion of Sources with Superluminal Velocity in Vacuum," Sov. Phys. Usp., vol. 15, pp. 184 -192, 1972.
- [3] M.V. Arkhipov, R.M. Arkhipov, Yu.A. Tolmachev, "Emission of a Spatially Modulated Resonant Medium Excited with Superluminal Velocity," Optics and Spectroscopy, vol. 112(2), pp. 243-248, 2012.
- [4] R.M. Arkhipov, I.Babushkin, M. K. Lebedev, Yu.A. Tolmachev, M.V. Arkhipov, "Transient Cherenkov radiation from an inhomogeneous string excited by an ultrashort laser pulse at superluminal velocity", accepted for publication in Phys. Rev. A.