Terahertz Superradiance of an Extended Electron Bunch Moving in an Oversized Corrugated Cylindrical Waveguide

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***Abstract*— We consider superradiance from an extended relativistic electron bunch moving in a periodically corrugated cylindrical waveguide for the generation of multi-megawatt terahertz pulses. To study this process, we have developed a self-consistent, quasi-optical theory which includes a description of the formation of evanescent wave near a corrugated surface and its excitation by RF current induced in the electron bunch.**

I. INTRODUCTION

In recent years, significant progress was gained in the generation of electromagnetic pulses in the centimeter and millimeter wavelength ranges based on the Cherenkov superradiance (SR) of high-current subnanosecond electron bunches propagating in periodically corrugated single-mode waveguides [1]. In these frequency ranges, SR pulses of subnanosecond duration with record-breaking gigawatt peak power were obtained. Development of Cherenkov SR sources operating at shorter wavelength bands, including the terahertz frequency range, is a natural continuation of this research [2].

II. BASIC MODEL AND RESULTS OF SIMULATIONS

For wavelengths shorter than one millimeter, conditions of ensuring the electron beam transport and reducing Ohmic losses imply the use of oversized slow-wave systems. Accordingly, it is necessary to use a quasi-optical approach for the description of Cherenkov radiation. In the case of a CW electron beams such an approach was developed in [3] for consideration of surface-wave oscillators. In this paper we demonstrate that a similar method can be effectively used for analysis of SR emission from extended electron bunches moving in oversized cylindrical waveguides with axial symmetrical corrugation $r = r_0 + \tilde{r}\cos(\bar{h}z)$, $\bar{h} = 2\pi/d$.

Radiated field can be presented as a sum of two counter-propagating TM-polarized wave-beams with the following components of magnetic field

$$H_\phi = \mathrm{Re}\left[H_+(z,r,t)e^{i(\omega_{br}t - \bar{h}z/2)} + H_-(z,r,t)e^{i(\omega_{br}t + \bar{h}z/2)}\right]. \quad (1)$$

Formation of evanescent wave and its excitation by the relativistic electron bunch can be described by equations

$$\frac{\partial A_+}{\partial Z} + \frac{\partial A_+}{\partial \tau} + \frac{i}{R^2}\left(\frac{\partial}{\partial\rho}\left(\frac{1}{\rho}\frac{\partial(\rho A_+)}{\partial\rho}\right)\right) = i\frac{\alpha}{R}\delta(\rho-1)A_- - \frac{G}{R},$$

$$-\frac{\partial A_-}{\partial Z} + \frac{\partial A_-}{\partial \tau} + \frac{i}{R^2}\left(\frac{\partial}{\partial\rho}\left(\frac{1}{\rho}\frac{\partial(\rho A_-)}{\partial\rho}\right)\right) = i\frac{\alpha}{R}\delta(\rho-1)A_+, \quad (2)$$

$$\frac{d\theta}{dZ} = \varepsilon^{-2}, \quad \frac{d\varepsilon}{dZ} = \mathrm{Re}\left(\frac{1}{R}\frac{1}{\rho}\frac{\partial(\rho A_+)}{\partial\rho}e^{i\theta}\right),$$

$$A_+\big|_{Z=0} = 0, \quad A_-\big|_{Z=L} = 0, \quad \varepsilon\big|_{Z=0} = 1, \quad \theta\big|_{Z=0} = \theta_0 \in (0, 2\pi].$$

where $G = \dfrac{eI_0}{mc^3}\dfrac{\gamma_0}{\bar{h}^2 b_e r_e}\dfrac{\partial}{\partial\rho}\left(f\left(\rho, \tau - \beta_0^{-1}Z\right)J\right)$, $\rho = \dfrac{r}{r_0}$, $R = \dfrac{\bar{h}}{2\gamma_0}r_0$, $Z = \dfrac{\bar{h}}{4\gamma_0^2}z$, $\tau = \dfrac{\bar{h}c}{4\gamma_0^2}t$, $\varepsilon = \dfrac{\gamma}{\gamma_0}$, $\alpha = \dfrac{\gamma_0\bar{h}\tilde{r}}{2}$, $A_\pm = i\dfrac{eH_\pm}{m\bar{h}c^2}$, $J = \dfrac{1}{\pi}\displaystyle\int_0^{2\pi} e^{-i\theta}d\theta_0$, $f(\rho,\tau)$ - electron beam distribution function.

Simulations of the Cherenkov SR were performed in the terahertz range (central frequency 350 GHz, Fig. 1a) for an electron bunch with a length of l_z^e=2.4 mm, average radius of $r_e = 1.7$ mm, thickness of $b_e = 0.1$ mm, particle energies of 0.5 MeV and a total current of 2 kA. The bunch is moving in a waveguide with a radius of $r_0 = 1.8$ mm, a corrugated region of length 2.3 cm, a corrugation period of $d = 0.45$ mm and an amplitude of $\tilde{r} = 0.15$ mm. Simulations showed that the main fraction of the radiation is emitted in the form of a short SR pulse in the positive direction of z axis, i.e., in the direction of propagation of the electron bunch. Amplitudes of both partial waves decay exponentially in the radial direction with increasing distance from the corrugated surface as shown in Fig. 2. The peak power of the SR pulse amounted to 65 MW at a pulse duration of ~15 ps.

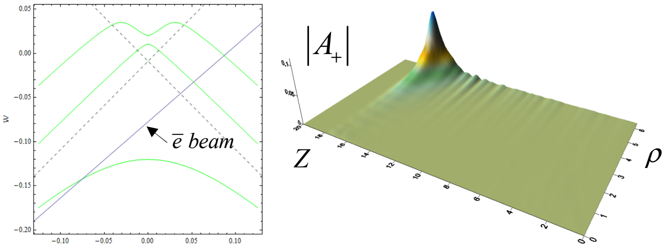

Fig. 1. (a) Dispersion characterisics of em wave (green lines) and electron beam (blue line). (b) Formation of SR pulse with excitation of evanescent wave

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