

THz radiation under non-central propagation of electrons through periodical channel

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Abstract. Radiation from non-central electrons moving through channel with variable radius in the THz region is investigated using Particle In Cell (PIC) solver of the Computer Simulation Technology (CST) software package. Characteristics of radiation arising for non-central and central electrons propagation in the channel are compared, both for Smith-Purcell and Cherenkov kinds of radiation. It is demonstrated that the radiation is more intensive for the non-central propagation of electrons.

1. Introduction

There is a variety of possible schemes for generation of electromagnetic radiation in the THz (terahertz) frequency range. Powerful THz sources can be based on polarization radiation, when radiation occurs due to polarization of material by electrons Coulomb field. Using the channel in matter allows not to damage the target. Mechanism of Cherenkov radiation is mainly used for generation of powerful radiation [1], including THz spectral range. In our recent paper [2] we investigated source of THz radiation based on electrons moving through the channel with variable radius (see Fig.1), when radiation arises due to Cherenkov (CR) and Smith-Purcell (SPR) mechanisms. It was shown that SPR can be used as powerful source of THz radiation. Along with that CR and SPR permit to design comparatively compact THz radiation source.

In this work we consider electrons propagating at distance y from axis z of corrugated dielectric channel, see Fig.1. Theoretical calculations for the non-central propagation of electrons gives ambiguous expressions which are not that simple to analyse, and numerical simulation is of great use for preliminary simulation. In order to create powerful THz source in future experiment at LUCX facility in KEK in Japan [3,4], it is of use to investigate radiation under non-central propagation. For this purpose we shall perform numerical simulation using Particle In Cell (PIC) solver of Computer Simulation Technology (CST) software package.

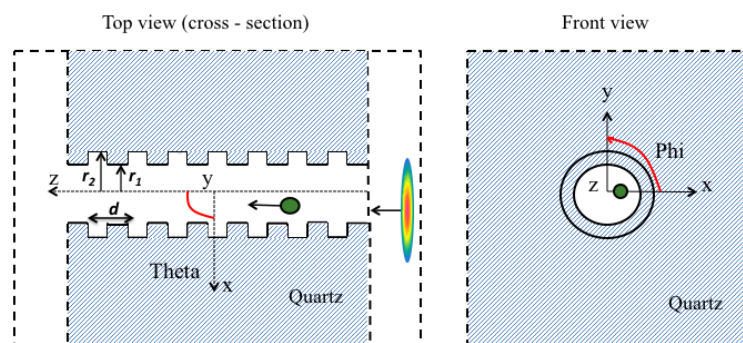


Figure 1. Scheme of THz source.

2. CST simulation of non-central propagation

In this section simulations of radiation emitted from non-central propagation through periodical channel in quartz will be discussed. Particle In Cell (PIC) solver of Computer Simulation Technology (CST) Particle Studio software calculates the development of the fields generated by a charged particle at discrete time samples. The fields are estimated at discrete points whereas the particles are tracked in continuous phase space. Values of the electric field are calculated at each discretization point in the domain, and the electric field values at the outer borders of the calculation domain are extrapolated into the wave zone [5] (which we can call also far-field zone), using the method described in [6].

Parameters of electron bunch and corrugated channel in material are shown in Table 1. Parameters in Table 1 were chosen to correspond to the experiment at LUCX. Internal radius r_1 was chosen to be larger in order to accommodate transversely larger bunch, propagating with an offset through the corrugated channel. Groove period and depth are chosen so that (-1) order of SPR corresponding to 300GHz is observed at the angle $\Theta = 89.94$ deg.

Parameter	Value
Bunch Lorentz-factor (γ)	16
Bunch charge	0.1 nC
Longitudinal charge distr. $\sigma_{long} = l_b$	0.1mm
Transverse charge distr. $\sigma_{transv} = r_b$	0.05 mm
Frequency	300GHz
Wavelength	1mm
Material	Quartz
Dielectric permittivity	$\varepsilon = 3.75$
Internal radius, r_1	1mm
Groove depth, $a = r_2 - r_1$	0.3mm
Number of periods	15
Groove width, l	0.75 mm
Grating period, d	1.5 mm

Table 1. Simulation parameters.

In order to compare CST simulation with future analytical formulas or experimental dates it is of great interest to investigate the radiation distribution in far-field zone. To assume far-field zone, the propagation distance in free space between the target and observation point must satisfy the condition $L \gg \gamma^2 \lambda$, L must be much larger than the formation length. Fig. 2 is plotted using data from Table 1.

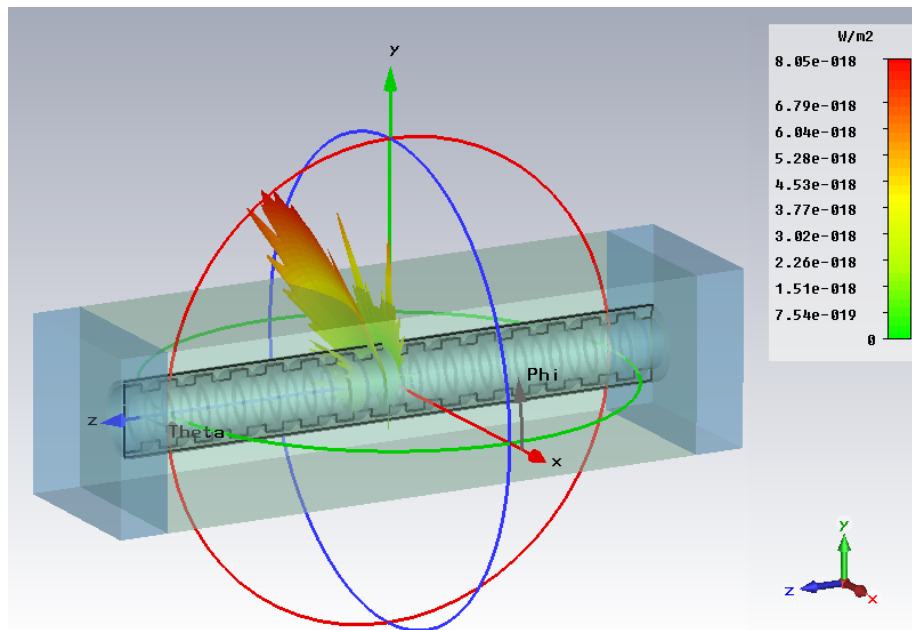


Figure 2. Radiation in the wave zone for the bunch position $y = 0.5 \text{ mm}$.

From Fig. 2 one may conclude that for $y = 0.5 \text{ mm}$ the radiation directivity is rather high, which is important from experimental point of view.

Now let us investigate and compare intensities for noncentral and central propagation of electrons for different bunch position (distances between bunch and axis y).

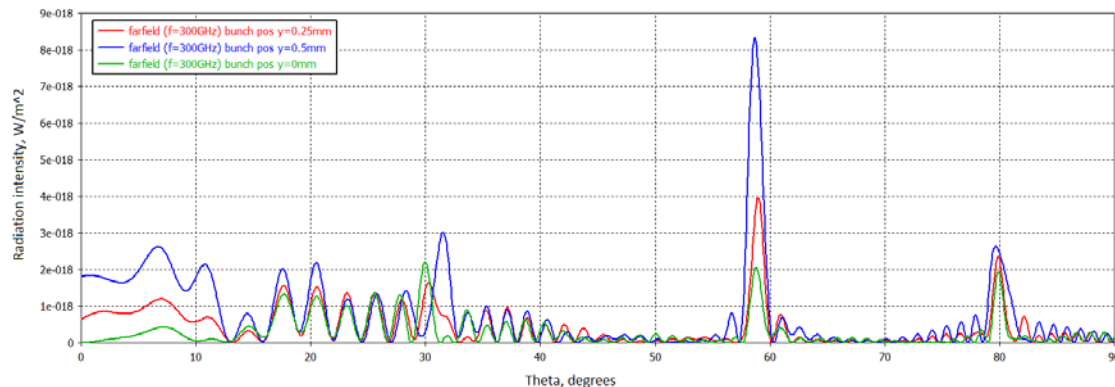


Figure 3. Dependence intensity on theta for different bunch positions.

As one can see from Fig. 3, the spectral-angular dependence on theta has several maxima, which correspond to SPR peaks for different m , $m = \frac{d}{\lambda} \left(\left(\beta \sqrt{\epsilon} \right)^{-1} - \cos \theta \right)$ – SPR dispersion relation and the Cherenkov radiation peak for $m = 0$. Another interesting fact: if we increase the distance between bunch and axis, the radiation intensity also changes, but dependence intensity on bunch position y is not linear. The spectral-angular distribution leads to the maximum value for $y = 0.5 \text{ mm}$, which corresponds to CR, and its contribution is more pronounced, that that of SPR. It is important to note that situation with comparison SPR and CR is not simple, and intensity of radiation strongly depends on bunch and target parameters [7].

Now we shall move on to the investigation of CR radiation in case of non-central propagation, because for simulation parameters from Table 1 CR is more intensive then SPR. Fig. 4 demonstrates the polar plots of the CR for the five values of the bunch position.

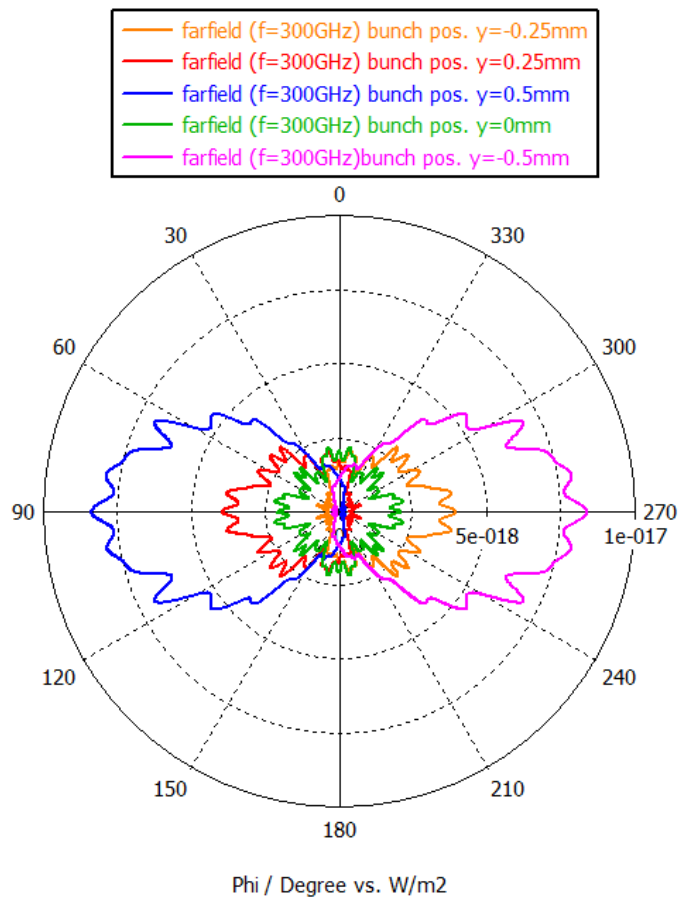


Figure 4. Polar plots for different bunch position.

We can see that the radiation is more intensive for the greater values of bunch position y . On the one hand, investigation of non-central propagation of electrons through corrugated channel can be useful for describing future experiment in LUCX facility in KEK. On the other hand, the problem of calculation of radiation is not that simple, and numerical optimization can be of great use. It means non-central propagation added one extra parameter, which should be optimized.

3. Conclusion

Non-central propagation of bunch of electrons through the channel shows two interesting features. First, without obtaining analytical expressions and corresponding optimization Cherenkov radiation can be more intensive as a THz source. Along with that the contribution of Smith-Purcell radiation seems to be comparable with CR. Radiation from non-central electrons moving through channel is proved to be more intensive, which is important from experimental point of view.

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