

# Terahertz pulses in a periodic plasma channel via modulated electron beam

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**Abstract.** The proposed scheme offers a promising way to study the effect of modulated relativistic electron beam in a periodic plasma channel (wiggler). The fluid equations model is used to find out the numerical behaviour of the radiation wave. In this scheme, a modulated relativistic electron beam makes possible to generate and amplify the high power terahertz (THz) radiation pulses. Using this model, we have analyzed and calculated the nonlinear dispersion relation of the radiation wave. The radiation frequency of THz wave can be tuned by varying the wiggler wavelength and beam energy. The excitation of the radiation wave is being developed with the resonance between the modulated frequency of electron beam and radiation wave in the periodic plasma channel (wiggler field) via Cerenkov interaction along the axial direction of channel, which provides the maximum enhancement in the growth rate of the radiation wave. Additionally, the growth rate of the unstable mode of the radiation wave depends on beam energy and modulation index, and becomes larger as modulation index approaches unity.

## 1. Introduction

Terahertz far-infrared radiation (THz) is considered to be the significant cutting edge of the electromagnetic spectrum for the last few decades, with various unique utility in high resolution imaging with medical application, security inspection, and remote sensing [1-4]. The THz radiation can be generated using various schemes such as ultra-short laser pulses [5] and quantum cascade lasers [6].

The conventional electromagnetic wiggler based FEL has been verified an effective source of generating short wavelength electromagnetic radiation but due to difficulties occurring in the designing of the practical implementations of such wigglers are limited. To overcome this limitation new plasma wigglers [7- 8] based FELs are introduced. The injection of an electron beam in a periodically system is a crucial example for the development of narrative radiation sources such as free electron lasers (FEL). In this paper, we present a scheme to generate and amplify Terahertz radiation using under-densitified plasma wiggler.

## 2. Model

Consider a density modulated relativistic electron beam of velocity  $v_b^0 \hat{z}$  and density  $n_b(n_b^0 + \Delta n_b^0 \exp[-i\omega t + i\omega z / v_b^0])$  is being introduced in ripple plasma wiggler of density  $n_w(n_w^0 + n_w^p \exp[i\vec{\omega} \cdot \vec{r}])$  with wave vector  $\vec{\omega}$ . Here, the terms  $n_p^0$  and  $n_w^p$  are the density of plasma electrons at equilibrium and perturbation, respectively. This non-linear interaction excites and



amplifies the THz electromagnetic wave ( $\omega_1 = 2\gamma_0^2 \omega_p^0, \vec{k}_1$ ) co-propagating with beam wave ( $\omega_1, \vec{k}_b$ ). The response offered by beam electrons and plasma electrons on account of THz radiation and beam wave is governed by the equation of motion

$$\frac{\partial}{\partial t}(\gamma_1 \vec{v}_{b1}) + (\vec{v}_{b1} \cdot \nabla) \gamma_1 \vec{v}_{b1} = -\frac{e\vec{E}_T^1}{m} - \frac{e\vec{E}_b^1}{m} - \frac{e}{mc}(\vec{v}_{b1} \times \vec{B}_T), \quad (1)$$

$$\frac{\partial n_{b1}}{\partial t} + \nabla \cdot (n_{b1} \vec{v}_{b1}) = 0. \quad (2)$$

After solving the equations (1) and (2) further, we get the perturbed velocity and density of the beam and plasma electrons, respectively. Consequently, this produces the nonlinear current density for THz radiation wave and beam wave. This nonlinear current density stimulate the excitation of the unstable radiation wave

$$\vec{J}_n^l = (\vec{J}_n^l)_T + (\vec{J}_n^l)_{beam} \quad (3)$$

Furthermore, using the Maxwell's third and fourth equations, we solve the wave equations and get the nonlinear dispersion relation and growth rate in unstable mode of radiation wave as follows

$$\lambda_w = \frac{4\pi c \omega_1 (\gamma_o^2 - 1) \cos(\psi)}{\omega_1^2 + \gamma_o^2 \omega_p^2}, \quad (4)$$

$$\beta = \left[ \frac{3}{16} \right]^{\frac{1}{2}} \left[ \frac{\omega_b^2 \omega_w^4 \omega_x^2}{\gamma_o^3 c^2 (\omega_p^2 + k_1^2 c^2)^{1/2} (k_b^2 - k_1^2)^2} \left( (1 + \Delta + (1 + \Delta) \gamma_o^2 \frac{\omega_x^2}{k_{bz}^2}) + \Delta \frac{k_o}{k_{bz}} \right) \right]^{\frac{1}{3}}. \quad (5)$$

where the terms  $\omega_b$ ,  $\omega_w$  and  $\omega_p$  are represented as beam plasma frequency, plasma wiggler frequency and electron plasma frequency, respectively in equation (5). This relation shows that the growth rate in the unstable mode of THz radiation wave depends on density of beam electrons or beam current, plasma electrons and inversely proportional to radiation frequency of the wave. Additionally, the above results can be extended to find out the efficiency of the radiation system.

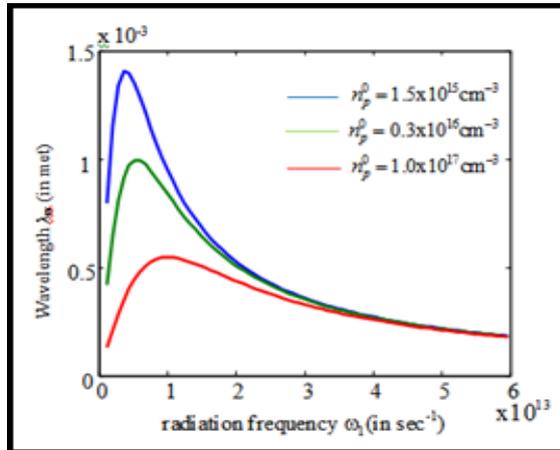
### 3. Results and Discussions

The results show that the amplification in growth rate of the unstable mode of wave is the sensitive function of the plasma density, beam current and modulation index. Using equation (4), the variation of radiation frequency versus plasma wiggler period is shown in figure 1. This figure illustrates that the wiggler period initially increases and then sharply starts decreasing as frequency increases further. In addition, as the plasma density increases more, the wiggler period becomes shorter and it could be more resonant to generate and amplify the coherent THz radiation. Using equation (5), figure 2 depicts the variation of growth rate of the radiation wave with beam density. This shows that growth rate increases as beam density increases. This result is in good agreement with the results obtained by [9-10]. From figure 3, it can be seen that the growth rate of the wave increases with modulation index but decreases as beam energy increases.

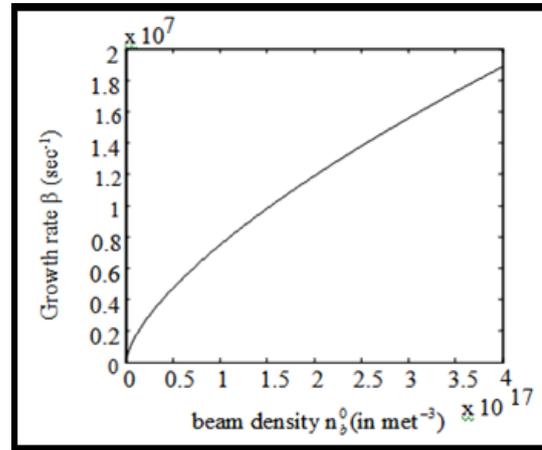
Using equation (4), in figure 4, we observe the variation of wiggler period with ripple angle and plasma density. This figure illustrates that the wiggler period decreases as ripple angle and plasma density increases and becomes sharper to amplify the THz radiation emission.

### 4. Conclusions

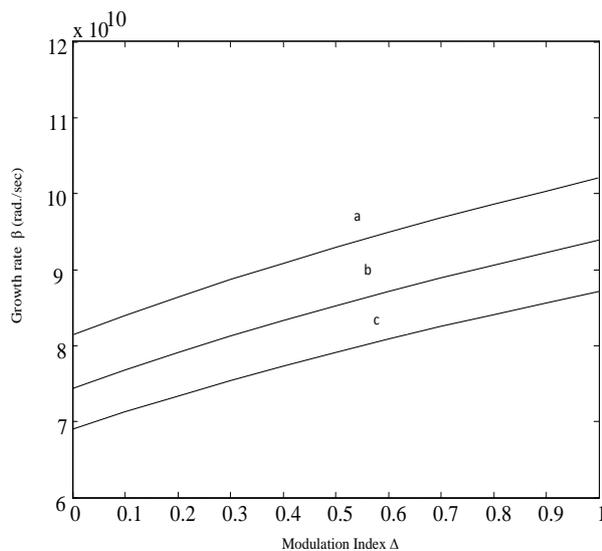
In summary, the interaction of pre-bunched relativistic electron beam with plasma kind of wiggler has been considered as one of the important alternative scheme to amplify the THz radiation emission. The present scheme reveals that the amplification of THz radiation wave depends on the beam energy, beam density, plasma density and modulation index and the desired radiation frequency can be tuned using plasma wiggler period and beam energy.



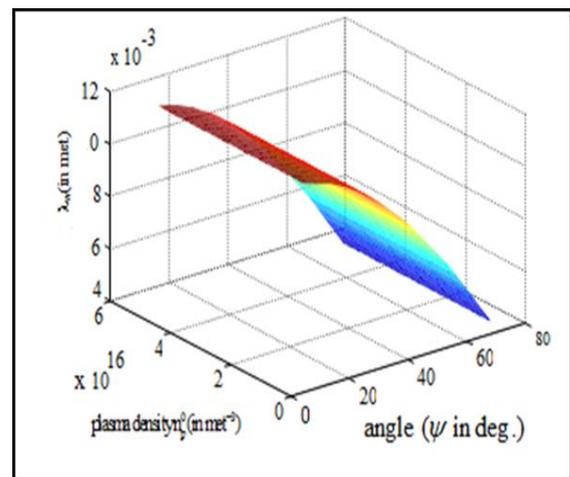
**Figure 1.** Figure showing that the periodic plasma wavelength decreases as plasma density increases and becomes sharper for THz radiation



**Figure 2.** Variation of growth rate  $\beta$  of radiation wave with beam density  $n_b^0$ .



**Figure 3.** Variation of growth rate ( $\beta$ ) with modulation index ( $\Delta$ ) at beam energy (a)  $E_b=1.0$  MeV (b)  $E_b=2.0$  MeV and (c)  $E_b=3.0$  MeV



**Figure 4.** Variation of periodic plasma wavelength  $\lambda_w$  with angle  $\psi$  and density  $n_p^0$ .

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