Study on Undulator Radiation from Femtosecond Electron Bunch

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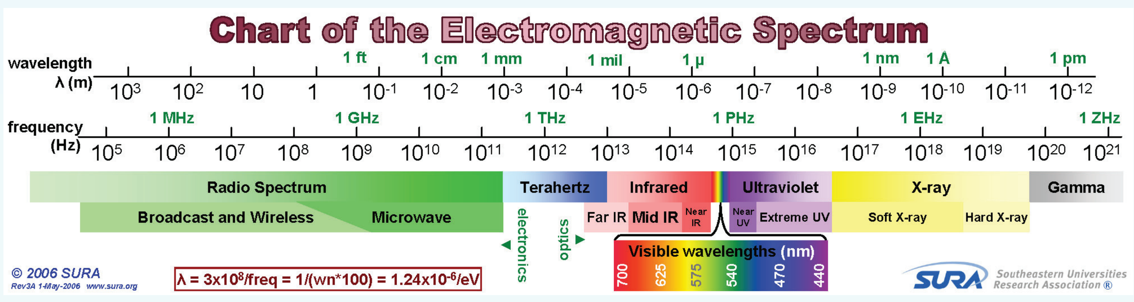
Abstract

Linac-based terahertzLinac-based terahertz (THz) source at the Plasma and Beam Physics (PBP) Research Facility, Chiang Mai University (CMU), Thailand, consists of a thermionic RF electron gun, an alpha magnet for magnetic bunch compressor, a travelling wave S-band accelerating structure for post acceleration, and various beam diagnostic instruments. The PBP-CMU linac system can produce relativistic femtosecond electron bunches, which are used to generate coherent THz radiation via transition radiation technique. To increase the radiation intensity, an electromagnetic undulator will be added in the beam transport line. The designed electromagnetic undulator has 35 periods with a period length of 64 mm and a pole gap of 15 mm. This study investigates the dependence of the electron beam energy and longitudinal bunch length on the coherent undulator radiation. The numerical simulation and procedure to generate the undulator radiation in the THz regime by using femtosecond electron bunches produced at the PBP research facility is reported and discussed in this contribution. Numerical calculation result shows that the energy of the undulator radiation, which is produced from electron bunches with an energy of 5 - 20 MeV, a peak current of 33 - 55 A, and an effective bunch length of 180 - 300 fs can reach 14 μJ.

Introduction

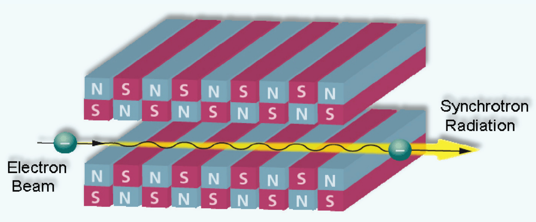
Current setup of the PBP-CMU linac.



Femtosecond electron bunches produced from the PBP-CMU linac can be used to generate coherent terahertz (THz) radiation via transition radiation or undulator radiation.

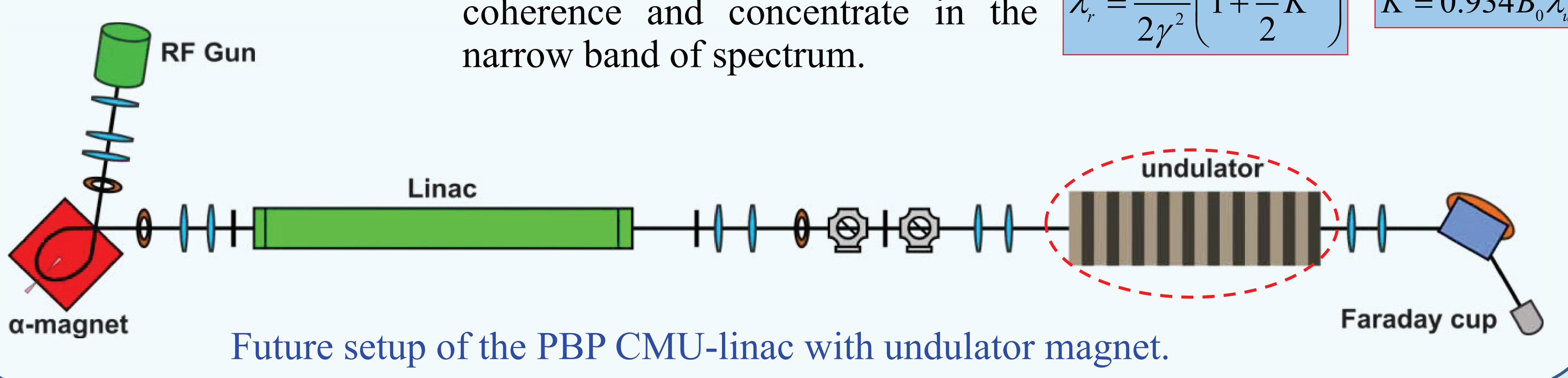
Undulator magnet consists of a periodic structure of dipole magnets. The static magnetic field (B_0) is alternating along the length of the undulator magnet with an undulator period length λ_u.

Relativistic electrons travelling through the periodic magnet structure are oscillating and thus emitting the radiation with the radiation wavelength λ_r. The undulator radiation is very intense, coherence and concentrate in the narrow band of spectrum.



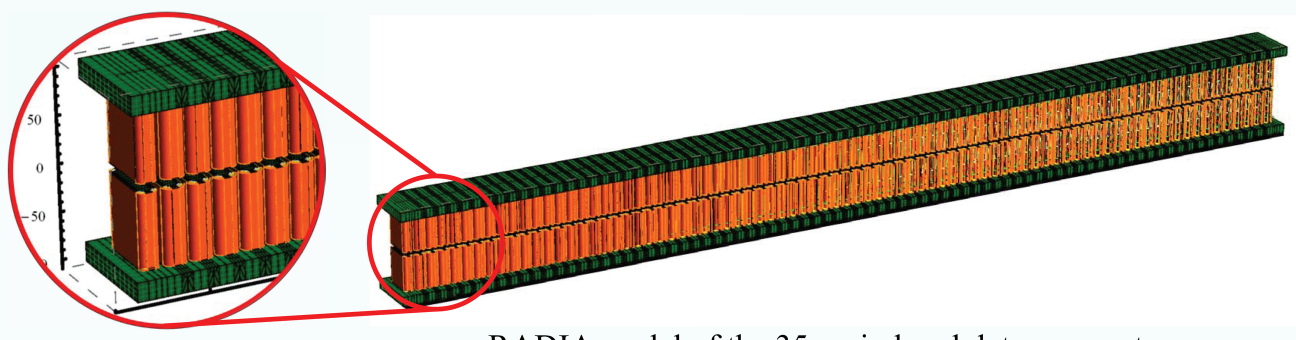
$$\lambda_r = \frac{\lambda_u}{2\gamma^2}\left(1+\frac{1}{2}K^2\right)$$

$$K = 0.934 B_0 \lambda_u$$



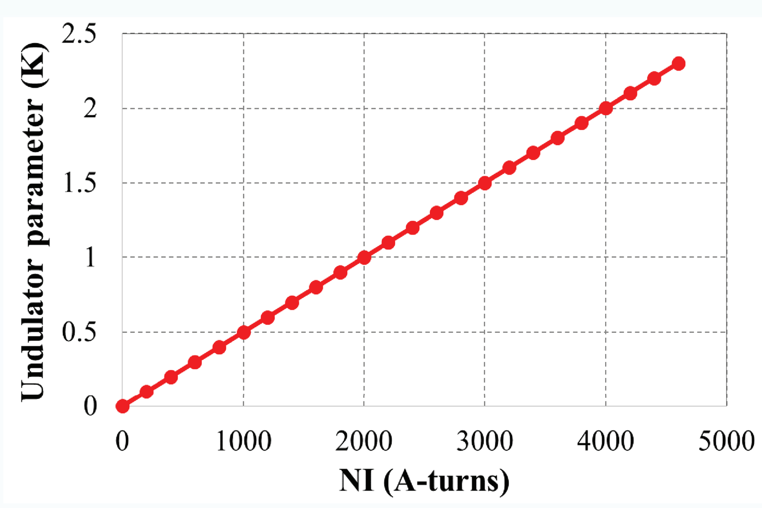
Future setup of the PBP CMU-linac with undulator magnet.

Undulator magnet

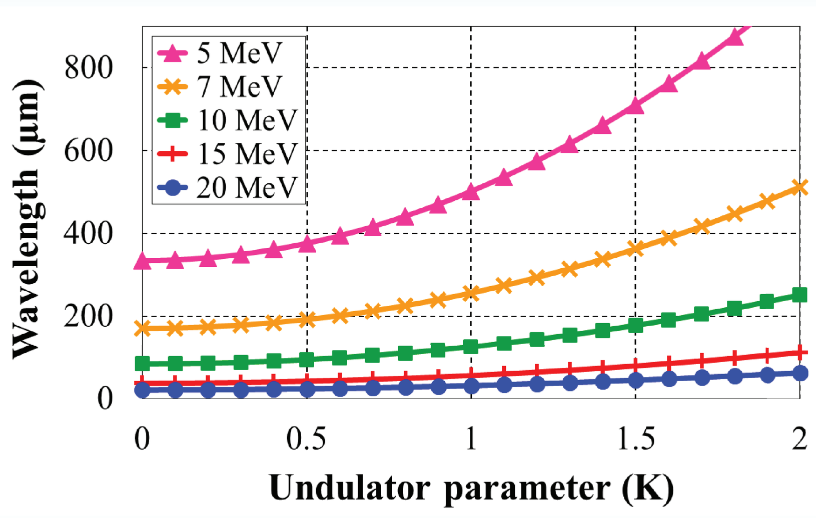


RADIA model of the 35 period undulator magnet

The undulator magnet is designed and simulated with the computer codes SUPERFISH and RADIA. This electromagnetic undulator consists of 81 magnet poles, return yokes and conducting coils. The number of period (Np) is 35 periods with a period length of 64 mm and the pole gap of 15 mm. The undulator parameter (K) or the magnetic field strength of the undulator can be adjusted by varying the coils' current or the width of the pole gap. Due to limitation of a vacuum chamber width located in the gap of the undulator, the desired undulator parameter will be reached by adjustment of the coils' current.



The undulator parameter as a function of the total current of the conducting coils.

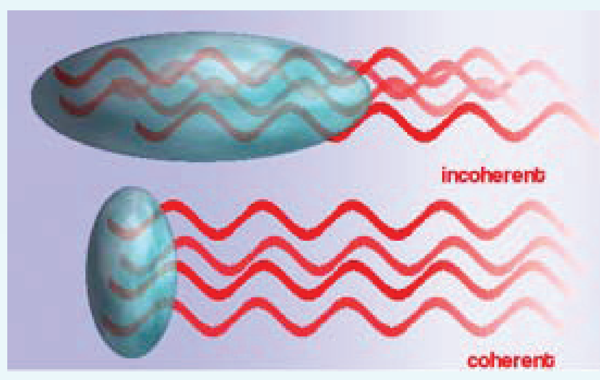


The undulator radiation wavelength vs. the undulator parameter for electron energies of 5, 7, 10, 15 and 20 MeV.

Currently, the PBP-CMU linac system can produce femtosecond electron bunches with a typical electron energy up to 15 MeV. Higher beam energies (~20 - 25 MeV) can be achieved with higher feeding RF power. To study the dependence of the undulator specifications on the electron beam energy, we consider 5 cases of 5, 7, 10, 15, and 20 MeV electron beams. The wavelength of around 30 - 500 μm can be obtained at the undulator parameter of 1 with the total current of 2000 A-turns for electron beam energies of 10 MeV.

Coherent Undulator radiation

The undulator radiation emitted from relativistic electrons subjected into periodic fields will be considered as the coherent synchrotron radiation (CSR) when the electron bunch length is equal or shorter than the radiation wavelength. This leads to properly add up of the emitted radiation from individual undulator poles in the forward direction and results in the enhancement of the radiation brightness as the brightness of the coherent radiation is proportional to the electron number squared.



Comparison of incoherence and coherence synchrotron radiation.

The total CSR energy (W_{coh}) depends on the radiation energy of a single electron (W_{1e}), the number of electron (N_e) squared, and the form factor (f_k) squared. Typically, the form factor of the electron beam with the bunch length (σ) can be estimated to be the Gaussian distribution with a standard deviation (σ), where $k = 2\pi / \lambda_r$ is the wave vector.

$$W_{coh} = W_{1e} N_e^2 f_k^2$$

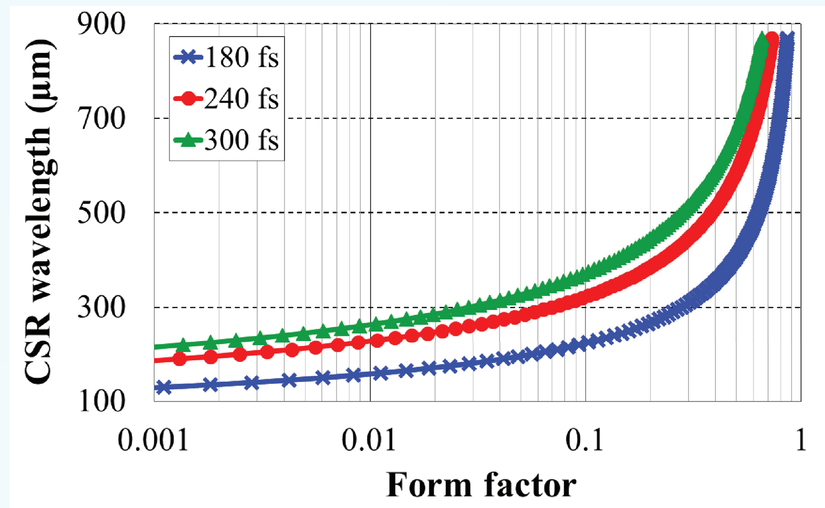
$$W_{1e} = \frac{N_p q_e^2 \pi}{3\varepsilon_0 \lambda_p} K^2 \gamma^2$$

$$f_k = e^{-\sigma^2 k^2}$$

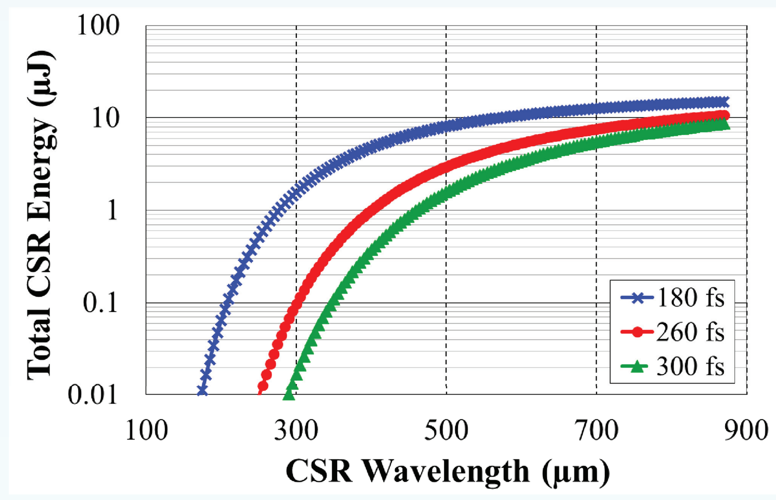
Summery of electron beam properties of the PBP-CMU linac and the designed undulator magnet

Parameters	Value
• Electron beam (@ undulator entrance)	
Electron energy (MeV)	5 - 20
Bunch charge (pC)	25
Bunch length (fs)	180 - 300
• Undulator magnet	
Undulator parameter	≈1
Period length (mm)	64
Number of periods	35
Pole gap (mm)	15

The form factor is smaller when the electron bunch length increases or the electron bunch expands longitudinally. The calculation results show the proportional relation between the CSR wavelength and the form factor of electron beam. The radiation wavelength range generated from the short electron bunch is broader than that of the long electron bunch when considering in the form factor of 0.001 - 1.



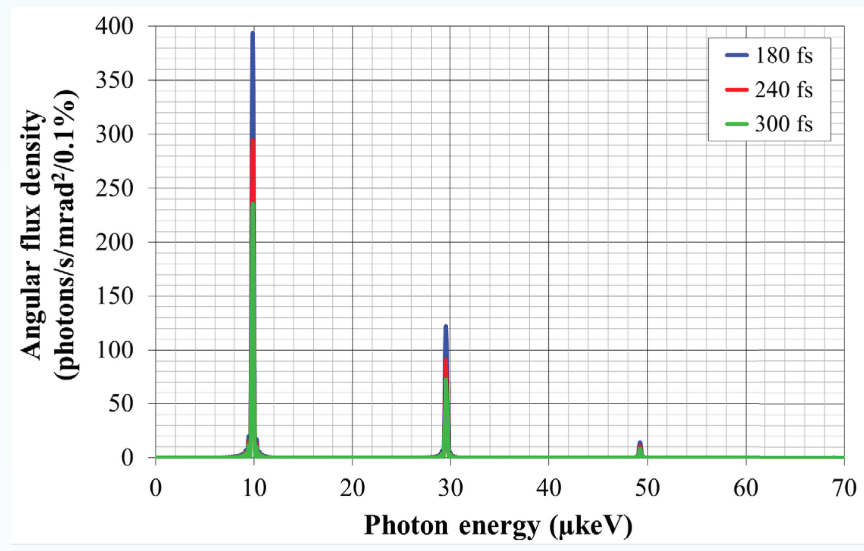
The electron form factor as a function of the CSR wavelength for the electron bunch length of 180, 240 and 300 fs.



The total CSR energy as a function of the CSR wavelength for the electron bunch length of 180, 240 and 300 fs.

The graph indicates that the total CSR energy is logarithmically increases and then saturates up to about 10 μJ at the CSR wavelength of 800 μm for all three bunch lengths. When the 10 MeV electron beam with a bunch length of 180 fs and a bunch charge of 25 pC travels in the magnetic field of the undulator magnet with the undulator parameter of 1 and the undulator gap of 15 mm, the CSR energy of up to 14 μJ per microbunch can be obtained.

Preliminary study of the spectrum is considered by using the ideal sinusoidal magnetic field with the 10 MeV electron beam and the peak undulator field of 0.1674 T (K ≈ 1). The result shows that the angular flux density at the fundamental harmonic for all electron bunch lengths is accomplished at the photon energy of 9.85 μkeV with a quasi-monochromatic peak of spectrum. Moreover, the angular flux density increases when the bunch length is shorter.



Angular flux density as a function of photon energy with the electron energy of 10 MeV for the bunch lengths of 180, 240, and 300 fs.

Conclusion

Preliminary study on coherent undulator radiation from femtosecond electron bunches was conducted. The undulator radiation wavelength and energy are tunable by adjusting the current of the conducting coils of the undulator magnet. The calculation results show that the radiation wavelength of around 30-500 μm can be obtained for the electron beam energies of 5-20 MeV. When the shorter electron bunch length is achieved, the short radiation wavelength is generated with the high radiation energy and high brightness. Further study with actual undulator magnetic field will be continued to study the performance of the set up.

Acknowledgements

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