CHAPTER 1

Introduction

Electromagnetic waves are utilized in many applications covering all fields for many years. A diagram of the electromagnetic spectrum with various applications corresponding to each radiation spectrum is shown in Fig. 1.1. In the last decade, electromagnetic radiation covering far-infrared (FIR) and terahertz (THz) regimes within a wavelength range of 100 - 1000 μm has become interesting spectrum in many applications, especially for the THz radiation. This radiation can pass through non-metallic materials, but it is reflected by metal and is absorbed by liquid. Due to this unique characteristic, THz radiation is used in several studies involving THz imaging for non-destructive analysis of different density materials. The THz imaging technique can be used to detect metallic and non-metallic weapons, explosive materials or drugs through concealing obstacles such as clothing or packaging. Therefore, it is useful for airport security, homeland security and defense [1]. Moreover, it is possibly used to observe the imperfection of integrated circuits e.g. semiconductor devices or electronic cards, which are enclosed in non-metallic packages [2]. A cavity in tooth enamel and cancerous tissue on skin can also be detected by using THz imaging [3].

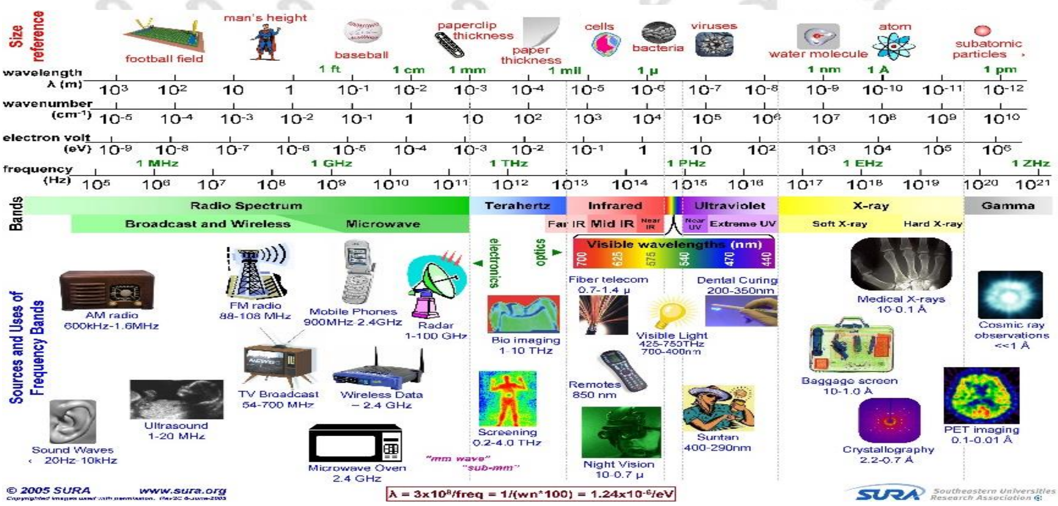

Figure 1.1: Electromagnetic spectrum diagram [4].

In addition, the frequency range of the THz wave corresponds with rotational and vibration modes of many bio-molecules. Therefore, THz radiation can be used to study the characteristics of various intermolecular bonds, such as hydrogen bonding, Van der Waals forces, and molecule-ion attractions. The well-known technique, which is used for such study, is called THz spectroscopy. This technique is very useful for medical identification, crystal polymorphism analysis, and DNA structure study. The various useful applications of THz radiation lead to broad studies on development of THz light sources, detectors, and several experimental techniques.

Development of femtosecond electron bunches to generate coherent FIR and THz radiation was established for the first time in Thailand and in the South-East Asia at the Plasma and Beam Physics (PBP) Research Facility, formerly the Fast Neutron Research Facility (FNRF), Chiang Mai University. The accelerator system at the PBP-CMU Linac Laboratory discussed in this thesis is composed of an S-band RF gun as a thermionic cathode electron source, an alpha magnet (α-magnet) as a magnetic bunch compressor, an S-band travelling wave linear accelerator (linac), and experimental stations for generating the THz radiation via transition radiation (TR) technique. Several steering magnets (ST) and nine quadrupole magnets (Q) are used to control the beam position and the transverse beam size throughout the beamline, respectively. Schematic drawing of the PBP-CMU Linac beamline is shown in Fig. 1.2.

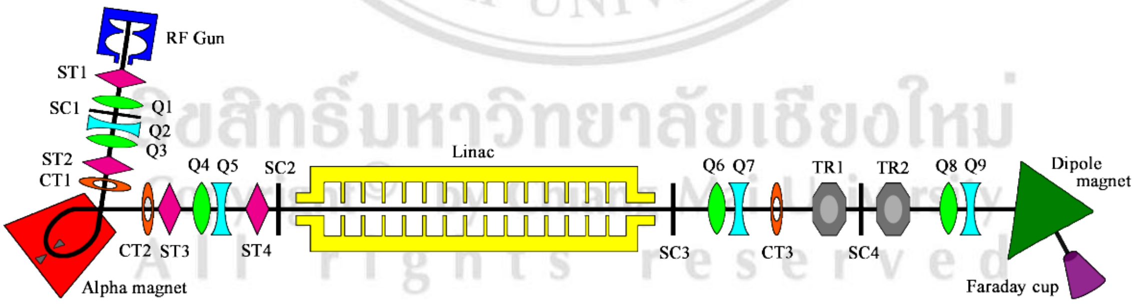

Figure 1.2: Schematic drawing showing the components of the PBP-CMU Linac system.

A thermionic RF-gun, an alpha-magnet, a post acceleration linac, and other components were installed and commissioned in 2005 [5]. The electron beam qualities were measured after the RF-gun and the linac by using several diagnostic instruments, which consists of current transformers (CT) for measuring the electron macro-pulse current and macro-pulse length, screen stations (SC) for observing the transverse beam profile, a Michelson interferometer for bunch length measurement and a Faraday cup for measuring the electron pulse charge at the end of the beamline. In addition, we use energy slits located inside the alpha magnet vacuum chamber and a dipole magnet for electron energy measurements after the beam accelerating in the RF-gun and the linac, respectively. The considered properties of electron beam produced from the PBP-CMU Linac system (as shown in Table 1.1) were measured in 2011, when the RF-gun and the linac were operated with a RF-pulse length of 2.8 μs and 8 μs, respectively. Both systems were operated at a repetition rate of 10 Hz [6].

Table 1.1: Measured beam parameters of the PBP-CMU Linac in 2011 [6].

Parameter	RF-gun	Linac
Beam energy (MeV)	2.0 - 2.5	8 - 12
Pulse current (mA)	700 - 1000	5 - 150
Number of electron per bunch	1.4×10^9	1.4×10^8
Bunch length (fs)	-	200 - 225

Electron beam with optimum parameters were used to generate the first THz radiation by using the transition radiation technique in March 2006. The spectrum of the THz transition radiation generated from electron beam with an energy of 10 MeV and a bunch length of about 200 fs covers the broad wavelength range of up to 125 μm with the radiation energy of around 9 - 22 μJ per macro-pulse [6]. The produced THz radiation was used to create THz images via a transmission mode of imaging technique for several samples such as cut-pattern in Al-foils, raw and cooked rice grains, water drop, and a fresh leaf [6].

Currently, a plan to increase the power of the THz radiation by using a coherent undulator radiation method is considered. This is in order to apply the THz radiation in various researches and applications with high resolution and brightness. An undulator magnet was theoretically studied for the first time as a radiation source by V. L. Ginzburg in 1947 [7]. It was first used to produce synchrotron radiation in visible regime. The undulator radiation has been increasingly developed and extended into the UV and X-ray radiation as appeared currently in many researches. The undulator magnet is classified as a permanent magnet, an electromagnetic magnet, and a superconducting magnet. Permanent materials such as NdFeB or Sm_2Co_{17} can be used to construct a short-period undulator magnet with higher magnetic field than that of the electromagnetic undulator, while higher peak magnetic field than 2 Tesla (T) can be produced from a superconducting undulator [8]. The primary advantages of the electromagnets are low-cost for construction and convenient change of the magnetic field by adjusting the applied current of the conducting coils. In this study, we focus on an electromagnetic undulator magnet to produce coherent radiation from short electron bunches.

Optimizations and analysis of the electron beam properties throughout the injector system, the post acceleration linac and the downstream beam transport line to reach the experimental station are hence necessary in order to investigate the capability of electron beam production and transportation along the components of the beamline. Then, electron beam qualities at the experimental station are used to estimate the possibility of coherent undulator radiation production. Typically, the electron beam brightness (B_e) is defined in terms of beam peak current (I_{peak}) per unit solid angle $(d\Omega)$ per unit area (dA) expressed by [5]

$$B_e = \frac{d^2 I_{peak}}{d\Omega dA} = \frac{d^4 I_{peak}}{d\sigma_x d\sigma_y d\sigma_{x'} d\sigma_{y'}} = \frac{d^2 I_{peak}}{d\varepsilon_x d\varepsilon_y}, \tag{1.1}$$

where $\varepsilon_x, \varepsilon_y$ are transverse beam emittances corresponding to the area of the transverse phase spaces $(\sigma_x, \sigma_{x'})$ and $(\sigma_y, \sigma_{y'})$. The peak current is the ratio of the electron bunch charge and the bunch length. According to Equation (1.1), a high brightness electron beam with high peak current and small emittance will provide high brightness or high intensity undulator radiation.

The main objective of this research composes of two parts. First, start-to-end beam dynamic simulations by using programs PARMELA and ELEGANT were performed based on the measured beam properties. This is in order to determine the appropriate operation parameters of the PBP-CMU Linac system for generating the coherent undulator radiation. The considered parameters for the simulation are a gradient of the alpha magnet, a minimum energy filter by using energy slits inside the alpha magnet vacuum chamber and an RF-phase of the linac. The procedure and results of the beam dynamic simulation are described in Chapter 3. The second part is about a study of the coherent THz undulator radiation. The considered properties include a spectrum range, a radiated power, and a radiation brightness. The measured parameters of electron beam in Table 1.1 and the properties of the optimal simulated beam from Chapter 3 were used to calculate the properties of the coherent undulator radiation at the experimental station. This was conducted in order to estimate the performance of the undulator radiation production by using the electron beam generated from the PBP-CMU Linac system. Details of this study was presented and discussed in Chapter 4. The related theory and principles in Chapter 2 consist of the principle of electron acceleration in a thermionic RF-gun, the bunch compression in an alpha magnet, the particle acceleration and energy gain from the electromagnetic wave in the linac, the space charge effects, the electron beam focusing and deflection by using a quadrupole and a steering magnet. The principles and related information for beam dynamic simulation with programs PARMELA and ELEGANT were also included in Charter 2. Furthermore, theories to explain radiated power and brightness of the coherent undulator radiation in a central cone and the transition radiation were described in this chapter. The final chapter (Chapter 5) concludes all information and details of my thesis.