ABOUT BPMS TO BE USED FOR PAL-XFEL*

H. Choi†, S.-J. Lee, H. Yang, C. Kim, S.-H. Kim, S.-J. Park, H.-S. Kang,
Department of Accelerator, PAL-XFEL, Pohang 790-784, Korea

Abstract

Pohang Accelerator Laboratory (PAL) has been building the X-Ray Free Electron Laser (XFEL), a fourth-generation accelerator, and the construction will be complete in 2015 [1]. To successfully construct the XFEL, PAL built an injection test facility (ITF) in 2012, and the facility is in operation. The ITF examines the efficiency of various diagnostic units through extended tests [2]. A BPM is a diagnostic unit that measures the position of an electron bunch. There are various kinds of BPM, and they have different merits and demerits. A user can select any kind of BPM that is appropriate for their purpose, and install it after going through various design and production processes. In order to measure the position of an electron bunch, a cavity BPM is installed at an undulator of PAL-XFEL and a stripline BPM is installed at an accelerator. The efficiency of the stripline BPM was tested at the ITF. The X-band cavity BPM was produced and is being tested at the ITF. This paper aims to introduce the specification and properties of the cavity BPM and stripline BPM to be installed at PAL-XFEL, and explain the physical concept and the way of measuring necessary for designing a stripline pickup.

INTRODUCTION

In PAL-XFEL, (a) Stripline BPM (S-BPM) (b) Cavity BPM (C-BPM) and (c) Energy BPM (E-BPM) are going to be installed and operated. A total of 60 S-BPMs are to be built in the 710m linear accelerator section. In the 220m undulator section, a total of 50 C-BPMs are going to be installed by building a C-BPM in every undulator unit. A total of four E-BPMs with one per bunch compressor in the linear accelerator is going to be built.

BPM PHYSICAL CONCEPT

The purpose and function of BPM is to detect an electromagnetic field that is produced in an electron bunch, which passes very fast, with $\beta > 0.5$ as speed of light, and examine the positions that the electron bunch passes through. An electromagnetic field, a generated physical phenomenon, is determined by the properties of an electron bunch (charge quantity, speed β, size, length, bunch interval, etc.) and it appears in various shapes. Prior to selecting an appropriate type of BPM, a physical phenomenon which is generated in an electron bunch should be counted [3]. It is planned to operate PAL-XFEL at 60Hz, bunch charge 1~200pC, bunch length 20 μm (60fs), energy 10GeV and Two-bunch mode separation 30~50ns. First of all, check the operation method of BPM and where to install it. And then discuss with an RF receiver engineer the selection of the BPM pickup frequency and finally talk to a data acquisition (DAQ) programmer to determine the type of digitizer board and data processing algorithm. See Fig. 1 for the process of discussing BPM related matters.

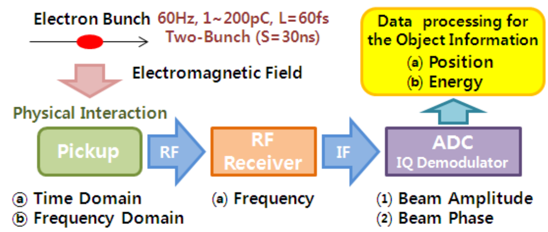

Figure 1: BPM construction process.

An electromagnetic field that is produced in an electron bunch is an impulse-form, which has a very instant producing time and a broadband (from DC to tens-of-GHz) for measurable frequency band. Time domain and frequency domain for impulse-form are shown in Fig. 2 [4]. For these reasons, measurement of performance of BPM pickup requires a high-speed oscilloscope (20GHz, 40GS/s), a broadband spectrum analyzer and a network analyzer.

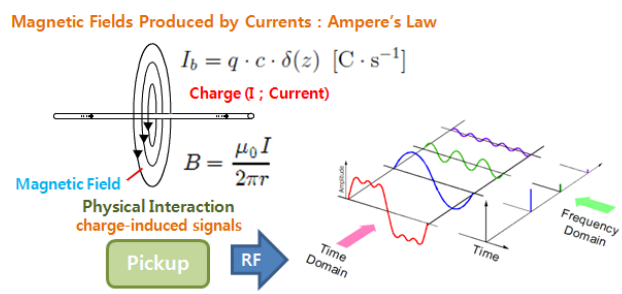

Figure 2: Impulse form.

The position resolution of BPM is determined by the physical interaction between the electromagnetic field (frequency, phase, amplitude), which is produced in the electron bunch, and the pickup, and is also related to pickup sensitivity [5]. A great deal of attention and carefulness are necessary in designing the BPM pickup and RF receiver to minimize noise factors. The RF receiver's signal-to-noise ratio (SNR) plays an important role in position resolution but initially designing a SNR-friendly BPM is more important. In addition, process tolerance factor and surface preparation are also crucial for BPM performance in the process of making BPM instruments. The resolution step ($V_{R=1}$ μm) of the IF signal which is generated by the RF receiver has to bigger than the noise factor (V_N) to be classified as a resolution step in the ADC process.

* Work supported by the Ministry of Science, ICT and Future Planning (MSIP) in Korea.
† choihyo@postech.ac.kr

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For multi-bunch operation, the time resolution of the pickup is crucial for dividing and detecting each bunch position. To improve time resolution, the Q-value and reflection elements of the pickup and RF receiver should be reduced. Design of all signal routes from BPM pickup's signal to digitizer should allow for impedance matching at center frequency f_0. See Fig. 3 for association between position resolution and time resolution [6].

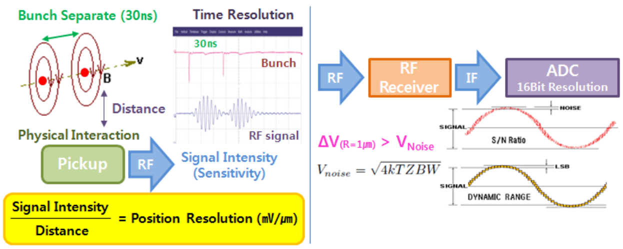

Figure 3: BPM resolution.

STRIPLINE BPM (S-BPM)

See Fig. 4 for how to design with coupling factor of S-BPM Pickup set as center frequency f_0. To get enough image current, the width (α) of Stripline can be changed by correlation between S-BPM's internal diameter and the bunch charge. Change of width (α) requires adjusting the height (d) space of the pickup for 50Ω impedance matching, according to the RF Microstrip calculation method [7].

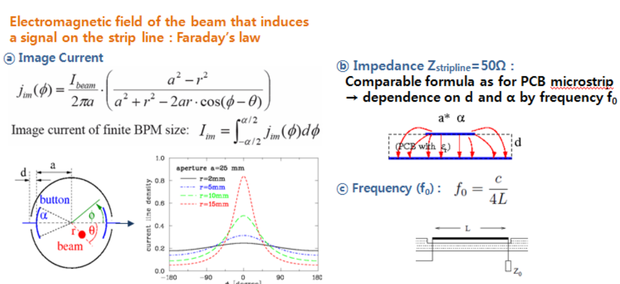

Figure 4: S-BPM Pickup design.

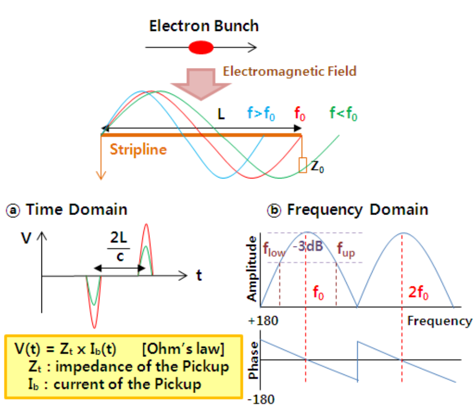

Figure 5: S-BPM Pickup signal.

See Fig. 5 for signal intensity from S-BPM pickup and frequency domain. If the electron bunch is bumped into the pickup or becomes too close, high voltage could flow into the RF receiver and cause malfunction. To prevent this, the RF receiver has to be equipped with a protection on the front end, such as a voltage limiter.

See Fig. 6 for the frequency spectrum which is produced in the process of the Fourier transform of the pickup signal of S-BPM, which is installed in PAL-ITF.

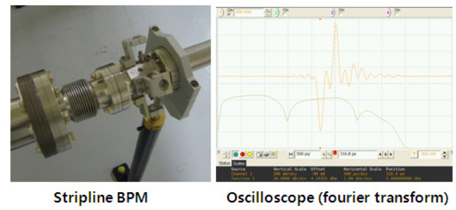

Figure 6: PAL-ITF S-BPM.

CAVITY BPM (C-BPM)

Significant physical concepts that need to be considered in designing C-BPM include i) the physical phenomenon taking place inside a cavity; ii) reason for having position information; iii) how to bring about only a frequency mode which has position information. See Fig. 7 for general design concept of C-BPM [8][9][10].

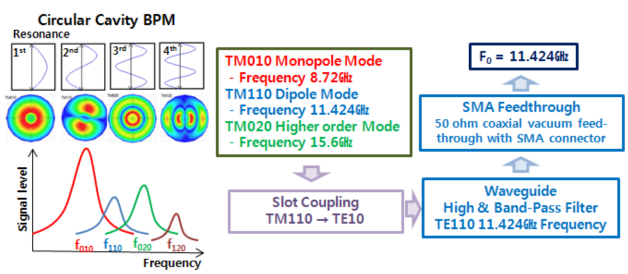

Figure 7: C-BPM design.

The physical phenomenon taking place inside the cavity is determined by a boundary condition effect, which is dependent on the cavity shape. In other words, a circular resonator will be designed to create a mode which can provide information on positions that the electron bunch has passed through, among the many electromagnetic fields that are produced when the electron bunch passes the center of the cavity. As shown in Fig. 8, the resonance frequency of f_{mnp} mode and mode shape are determined by the size of the resonator design.

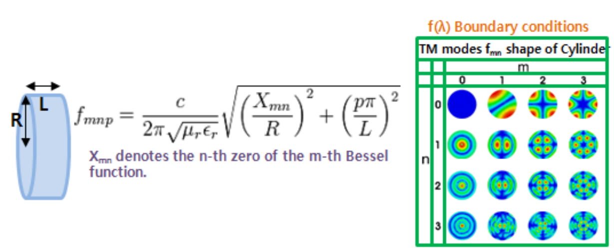

Figure 8: C-BPM resonator f_{mnp} mode.

Among the many resonant frequency modes that are produced when the electron bunch passes the center of circular cavity, the TM110 Dipole Mode has bunch position information. As shown in Fig. 9, when resonating,

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use a slot coupler on the inside wall of the cavity to couple a part of the TM110 Mode field and Waveguide TE10 Mode field.

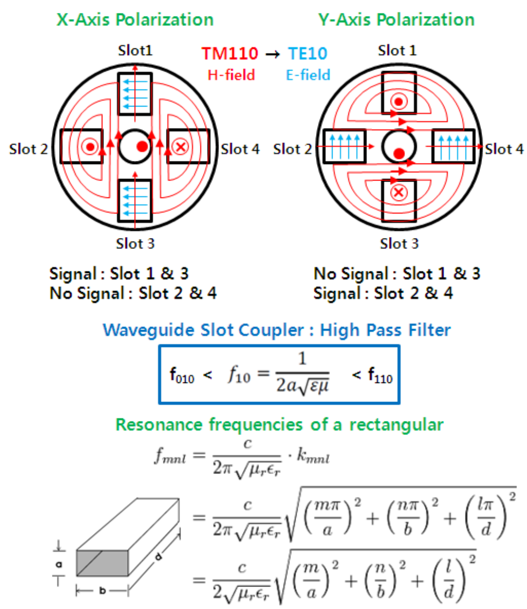

Figure 9: High-pass slot coupling.

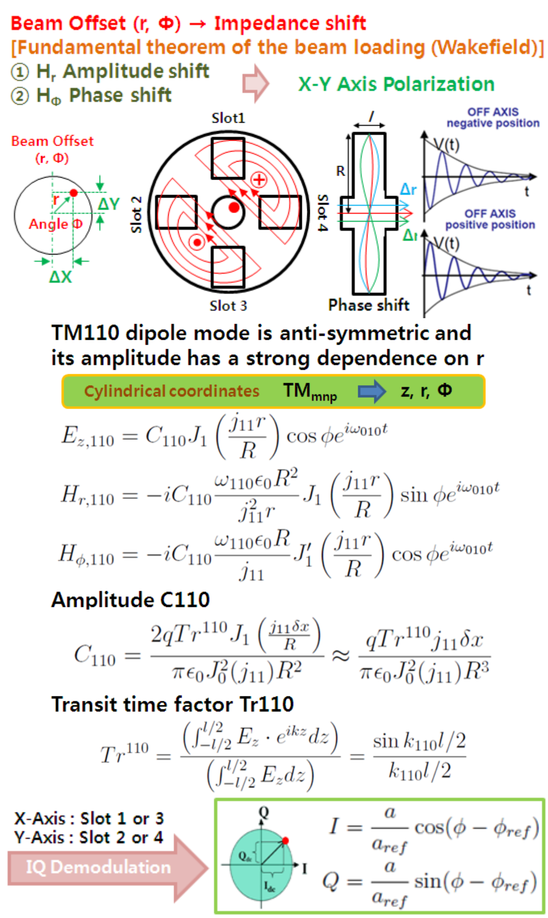

Figure 10: C-BPM X-Y position information.

Figure 10 explains how the TM110 Dipole Mode shows X-Y position information depending on X-Y position changes of the electron bunch through related formula [11][12][13][14].

There are many ways to extract the TM110 Dipole mode field formed inside the cavity. PAL-XFEL is designed to use a slot coupler to couple the TM110 Mode inside the cavity, employing a Waveguide- shape and high-pass filter and band-pass filter to deliver only the TM110 mode field to the end of the RF receiver. C-BPM is currently being produced and will be installed in PAL-ITF for testing. See Fig. 11 for the design structure of PAL-XFEL C-BPM [15].

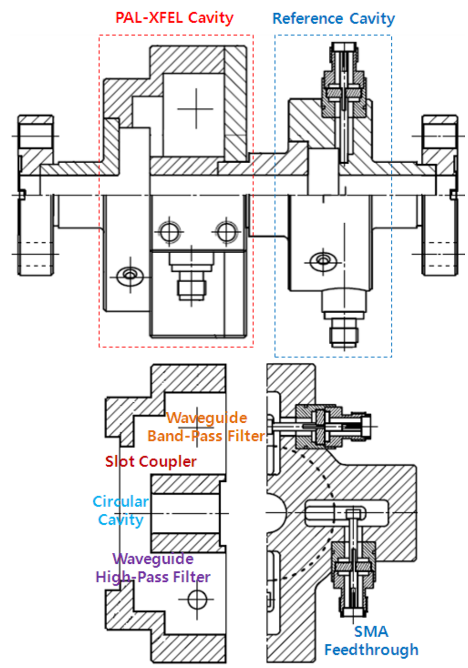

Figure 11: Layout of PAL-XFEL C-BPM.

ENERGY BPM (E-BPM)

The E-BPM that is attached to the PAL-XFEL bunch compressor (BC) uses a physical phenomenon, in which the bending angles of electron change in the bending magnet depend on electron energy. In Fig. 12, there is shown the BC concept map to be installed in the PAL-XFEL and energy bending phenomenon [16].

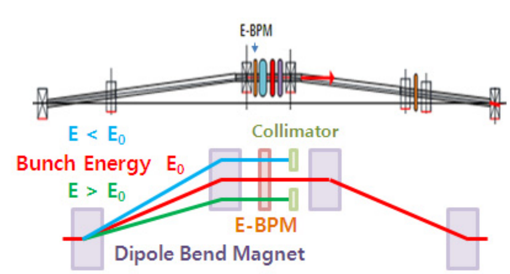

Figure 12: Layout of BC & Energy bending.

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According to the E-BPM operation principle, it is hard to detect the arrival time interval (2Δt) of the pickup pulse by an electronic device, as it depends on the positions (Δx) that the electron bunch passes through. The method in which an electronic device detects the phase difference (2ΔΦ) of Frequency f_0 taking place in the pickup pulse increases resolution. The required energy resolution by PAL-XFEL is ΔE/E = 0.1% (<5 μm). See Fig. 13 for E-BPM operation principle [17].

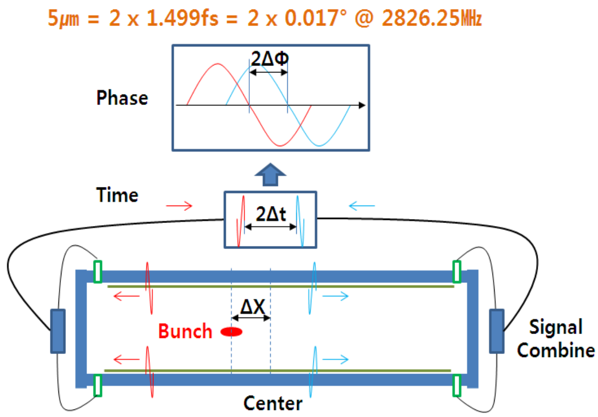

Figure 13: E-BPM operation principle.

E-BPM's pickup is made with Microstrip line. The size of the BC chamber determined the pickup frequency (f_0 = 2856.25 MHz) and the designed Microstrip line. See Fig. 14 for the pickup design concept. Microstrip wasn't used for high vacuum due to gas generated in substrates. However, as Microstrip materials usable for high vacuum are produced and sold, various BPMs with Microstrip line are expected to be applied to the accelerator area in the future.

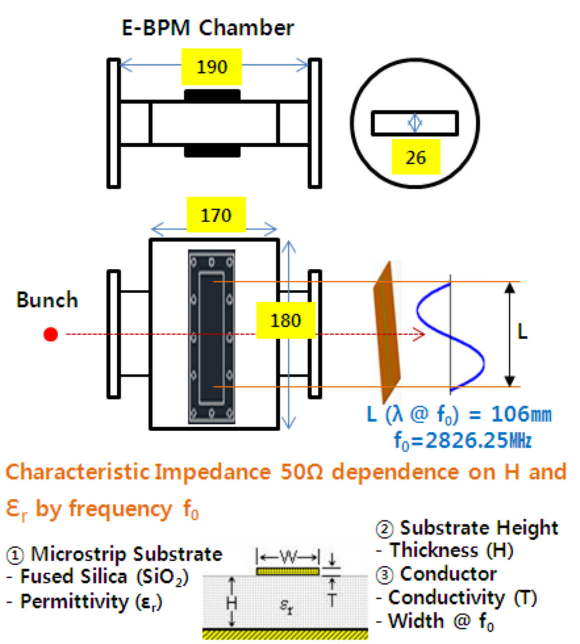

Figure 14: Layout of PAL-XFEL E-BPM.

FUTURE WORK

Manufactured and installed BPMs to be used in PAL-XFEL are either undergoing inspection or are ready to be produced after the pickup design has been completed. A future plan is to design and produce RF receivers and digitizers that are capable of the effective signal processing of pickup signals, while satisfying objectives.

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