BUNCH ARRIVAL TIME MONITOR TEST AT PAL-XFEL ITF

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Abstract

Femtosecond resolution electron bunch arrival time monitor (BAM) will be required for the beam-based RF phase feedback during PAL-XFEL operation. Two S-band cavity-type BAMs were manufactured for the test at the PAL-XFEL injector test facility (ITF). The resonance frequencies of the cavities are 2856 MHz and 2826.25 MHz. Electron beam induced signal from the cavities was digitized using a low level RF (LLRF) module. In this paper, the resolution of these cavities are analyzed and a possible improvement for better resolution are discussed.

INTRODUCTION

Two bunch arrival time monitor pickups with different resonance frequencies, 2856 MHz and 2826.25 MHz were designed and manufactured for the test at the PAL-XFEL injector test facility (ITF). When the low level RF (LLRF) module for the RF station at ITF, beam signal with the two resonance frequencies can be analyzed. 2856 MHz is the resonance frequency of the S-band used at PAL-XFEL. 2826.25 MHz is the frequency of reference signal in the LLRF module. In Table 1, the pickup parameters are summarized.

Table 1: BAM Pickup Parameters

Parameter		Value	Unit
Radius of Cavity	Type1	41.18	mm
	Type2	40.76	mm
Operating Frequency	Type1	2,826.25	MHz
	Type2	2,856	MHz
Coupling Coefficient		0.1	
Quality Factor		12,000	

Each pickup has a pill-box cavity and two pickup antennas. The cavity body is made from oxygen-free copper. The antennas are commercial feedthroughs. Both ends of the cavity are connected to 22 mm pipes and 2.75 inch flanges. The length of the pickup is 140 mm. The geometry of the pickup is shown in Fig. 1. The pickups were installed downstream of the second accelerating column where the beam energy reached 135 MeV as shown in Fig. 2. Figure 3 shows the layout of the ITF beamline. The beamline consists of an S-band photocathode gun, two S-band accelerating columns and S-band deflector.

For the signal processing, the LLRF system is employed. Because the LLRF PAD is similar to electronics of the BAM. In the LLRF system, the RF signal is downconverted to the Intermediate Frequency (IF) signal while keeping the information of the preserved signal. The IF signal is sampled using by 16 bit Analog to Digital Converter (ADC) at a constant sampling rate of 238 MHz. More detail on the LLRF system will be found in Ref. [1]. For the RF system, the RF frequency is 2,856 MHz, the LO frequency is 2,826.25 MHz, and then the IF frequency is 29.75 MHz.

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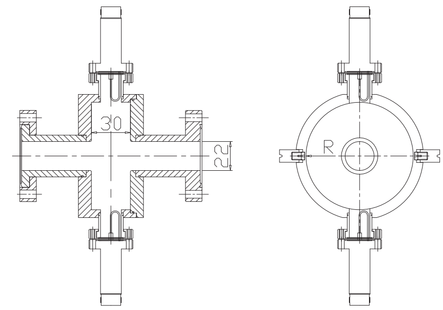

Figure 1: BAM pickup geometry. A half of the pickup is shown from the side (left) and front (right).

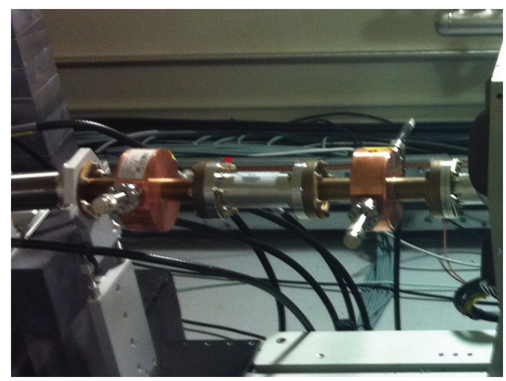

Figure 2: Photograph of the BAM pickups installed in the ITF tunnel.

MEASUREMENT

Voltage signal at 200 pC bunch charge was measured for the two types of pickups (Fig. 4. For the case of the Type1 pickup only beam signal was measured, while for the Type2 pickup dark current signal was measured together with beam signal. The dark current signal may impair the BAM resolution for the Type2 case, however the beam signal can be distinguished.

The phase information of bunch arrival time was extracted from the raw signal during 20 minutes for both pickups (Fig. 5).

The measurement resolution was estimated by comparing two signals from the two antenna installed in one pickup. The resolution of the Type2 pickup shows 2.5 fs better resolution compared with the Type1 pick (Fig. 6), however the difference is negligible.

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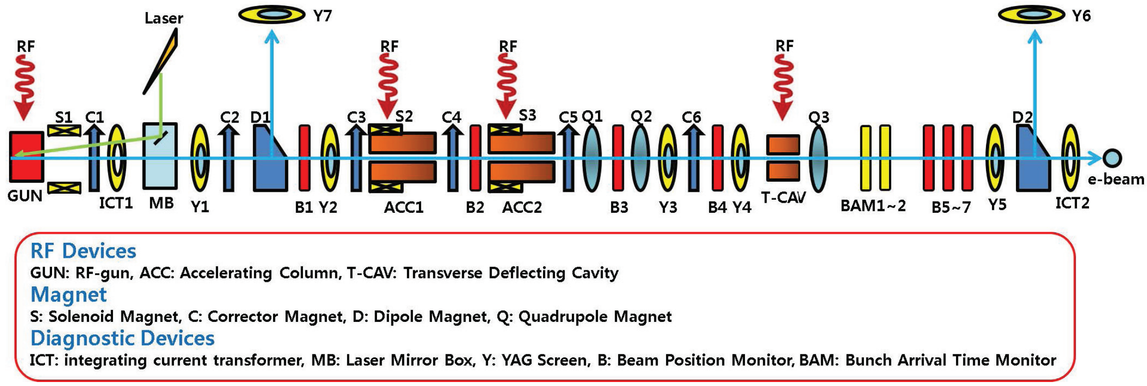

Figure 3: Schematic diagram of the ITF beam-line.

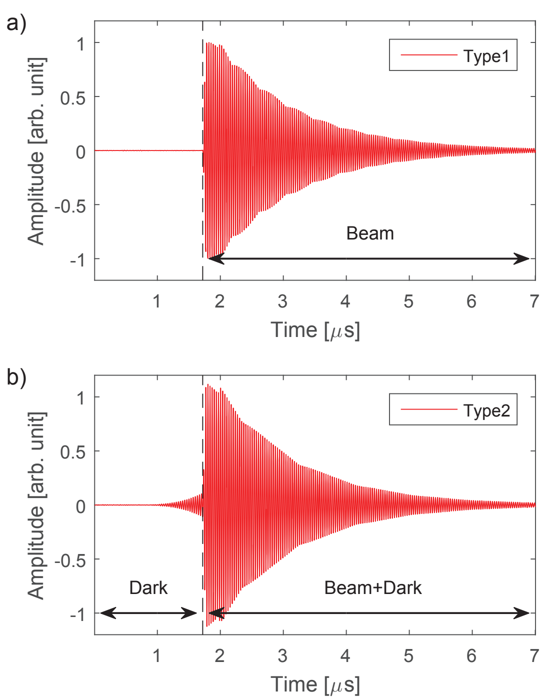

Figure 4: Raw voltage signal measured at 200 pC bunch charge from the Type1 pickup (a) and Type2 pickup (b).

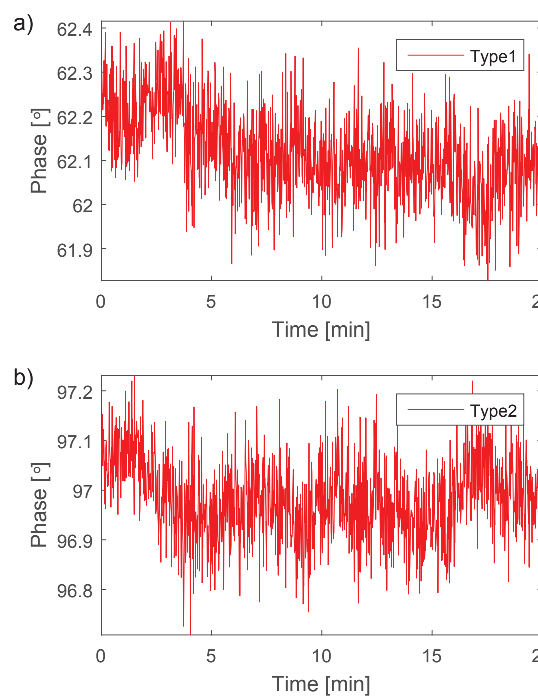

Figure 5: Short-term phase measurement at the bunch charge of 200 pC; a) Type1, b) Type2.

SIMULATION

For the simulation, signal-to-noise ratio (SNR) was defined as follows:

$$SNR_{\mathrm{rms}} = \frac{A_{\mathrm{Beam}}}{A_{\mathrm{Noise,rms}}},$$

where A_{Beam} is the amplitude of the beam voltage signal, $A_{\mathrm{Noise,rms}}$ is the rms amplitude of noise voltage signal. The beam voltage signal from the pickup was estimated by using the following relation:

$$y(t) = A_{\mathrm{Beam}} \exp(-t/\tau)\cos(\omega t - \phi_{0,\mathrm{Beam}}) + \mathrm{noise},$$

where t is time, τ is the decay time of the pickup, ω is the angular frequency of the pickup, and $\phi_{0,\mathrm{Beam}}$ is the beam arrival phase. In this equation, the voltage noise can be written as

$$\mathrm{noise} = A_{\mathrm{Noise,rms}} \times \mathrm{randn},$$

where randn is a MATLAB function to make normally distributed random numbers [2]. Resolution of arrival time was estimated as a function of SNR (Fig. 7).

For a better resolution, a high number of sampling is needed, but the resolution of the pickup depends on the sampling time window because the signal decays (Fig. 8). In an ideal case, the resolution of bunch arrival time measurement can be as good as 1 fs with 200 signal sampling.

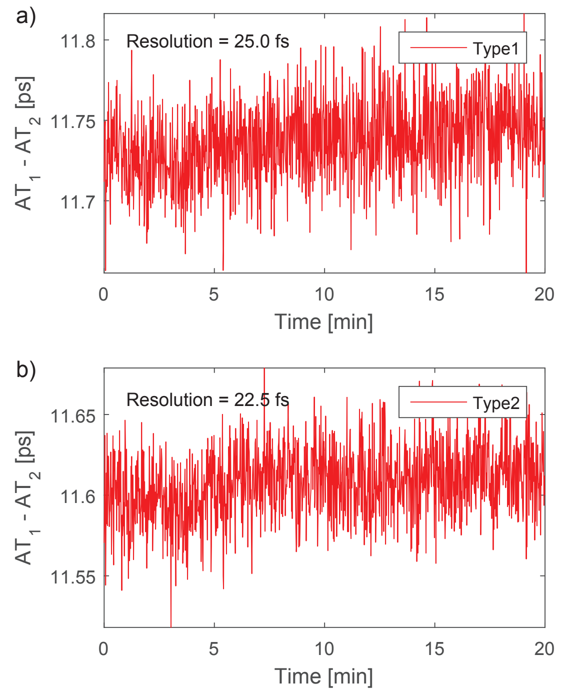

Figure 6: Short-term resolution measurement at the bunch charge of 200 pC; a) Type1, b) Type2.

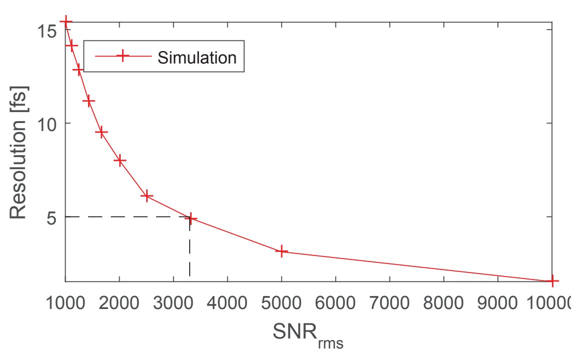

Figure 7: Resolution estimation as a function of rms signal-to-noise ratio (SNR). To achieve the 5 fs resolution, SNR should be better than 3300.

SUMMARY AND FUTURE PLANS

Two types of pickups were designed, manufactured and tested at PAL-XFEL ITF. The Type1 pickup with an operating frequency of 2826.25 MHz will be used as bunch arrival time monitor at PAL-XFEL. The Type2 pickup with an operating frequency of 2856 MHz may used also as bunch arrival time monitor even though the signal is contaminated with dark current. Therefore, the Type2 pickup will be used as dark current monitor at PAL-XFEL. When combined with the LLRF module, both pickups have 25 fs resolution at 200 pC bunch charge. The required BAM resolution at PAL-XFEL is better than 5 fs can be achieved with the pickup, however the SNR should be better than 3300.

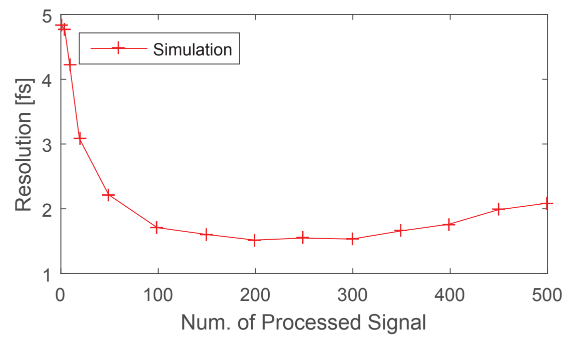

Figure 8: Resolution estimation as a function of sampling number over the signal for the case of 10000 signal-to-noise ratio. The sampling frequency is 238 MHz.

An analog front end for bunch arrival time monitor (Fig. 9), which will be used at PAL-XFEL instead of LLRF module, is under preparation. This type of front end will be installed in the PAL-XFEL tunnel to minimize signal loss. Once beam signal, 2856 MHz, is converted down to 29.75 MHz, the signal loss is reduced.

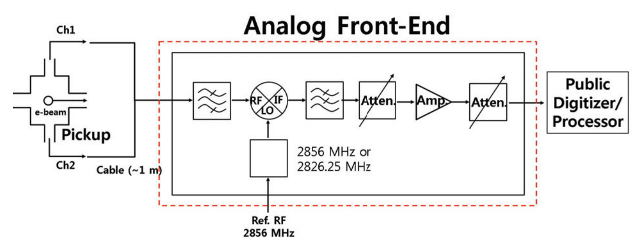

Figure 9: Schematic diagram of the analog front-end of beam arrival-time monitor.

REFERENCES

[1] J. Hu *et al.*, "Experimental Test of the Prototype LLRF Systems for PAL-XFEL", in *Proc. 5th Int. Particle Accelerator Conf. (IPAC'14)*, Dresden, Germany, June 2014, paper WEPME078, pp. 2462-2464.

[2] MathWorks, `http://www.mathworks.com`

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