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# BEAM ARRIVAL TIME MEASUREMENT AT SXFEL*

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*Abstract*

Shanghai Soft X-ray Free Electron Laser (SXFEL) is a fourth-generation light source which could provide coherent X-rays for various scientific researches. One of the key issues of its operation is the measurement of bunch arrival time because it is important for the synchronization of a bunch and seeded laser. The measurement utilized a newly designed beam arrival time monitor (BAM). The BAM contains two different frequencies of cavities. Thus a new scheme, dual-cavities mixing method, can be applied in this experiment to evaluate the beam arrival time resolution. In this paper, we presented the scheme, calculated the measured resolution with this method and evaluated the stability of the new monitor.

## INTRODUCTION

SXFEL is a XFEL facility and it is under construction [1]. For this facility, it is of importance to measure the beam arrival time within 100 fs to keep the synchronization of a bunch and a seeded laser. One method to conduct the measurement is to compare the phase difference between reference signal and measured signal. To reduce the noise introduced by the reference signal during transmission, a dual-cavity BAM was applied in this experiment. Since the high energy electron beam almost reaches the speed of light and the cavities distance is very short, the phase difference measured at the two cavities is constant. Thus the system errors from cavities cables and RF front-end electronics can be evaluated. In the preliminary work, we are committed to minimize these system errors as much as possible.

To carry out this experiment, a dual-cavities BAM was designed and the pickups were based on C-band monopole cavities [2]. Figure 1 shows the photograph of the prototype BAM.

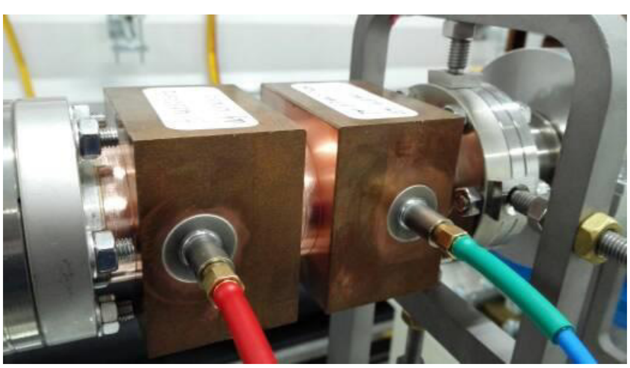

Figure 1: Photograph of the prototype BAM.

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The prototype BAM has been developed and installed at SXFEL. The two pickups work at 4.685GHz and 4.72GHz, respectively. The frequency difference of the two cavities is about 35 MHz. The distance between the two cavities is more than 60 mm to avoid the cavity crosstalk. Table 1 shows the parameters of the BAM pickups. The parameters were calculated by Computer Simulation Technology (CST) Microwave Studio.

Table 1: BAM Pickup Parameters

| Parameter | Value (#1) | Value (#2) | Unit |
|---|---|---|---|
| Frequency | 4.685 | 4.72 | GHz |
| Unloaded quality factor ($Q_0$) | 4796 | 4835 | - |
| External quality factor ($Q_e$) | 1.8e5 | 1.9e5 | - |
| Loaded quality factor ($Q_L$) | 4671 | 4716.4 | - |
| R over Q | 107.2 | 107.9 | Ohm |
| Bandwidth (BW) | 1.002 | 1.025 | MHz |
| Decay time constant (τ) | 317.7 | 318 | ns |

In this study, the beam induced signal from downstream pickup served as a local oscillator signal input to the mixer. And the RF signal form upstream pickup was used as input signal for the mixer. Thus an intermediate frequency (IF) signal of about 35 MHz were obtained.

## MEASUREMENT

There are four BAMs on the SXFEL facility. Two of them are installed at the drift section after the injection; the other two are placed in the modulator section. The experiment was conducted near the modulator because the noise in the experiment hall compared to the injection is smaller. Figure 2 presented the schematic diagram of the beam arrival time resolution evaluation [3]. An RF signal is generated when an electron beam passes through the BAM cavities. The RF signal was extracted with four antennas in the BAM wall and delivered to the RF front end in the experiment hall with long cables. The signals were processed with four channels of the RF front end system. In this system, two set of frequency mixer were applied for down conversion. The signals from port 1 and port 2 were used as local oscillator (LO) signal of mixer; signals from port 3 and port 4 were served as RF input signal. Then the low pass filters were used to filter out the high frequency signal, thus the IF signal was retained. A 12 bit Analog-to-Digital Converter (ADC) with a sampling rate of 500 MHz was then adopted to sample the IF signal.

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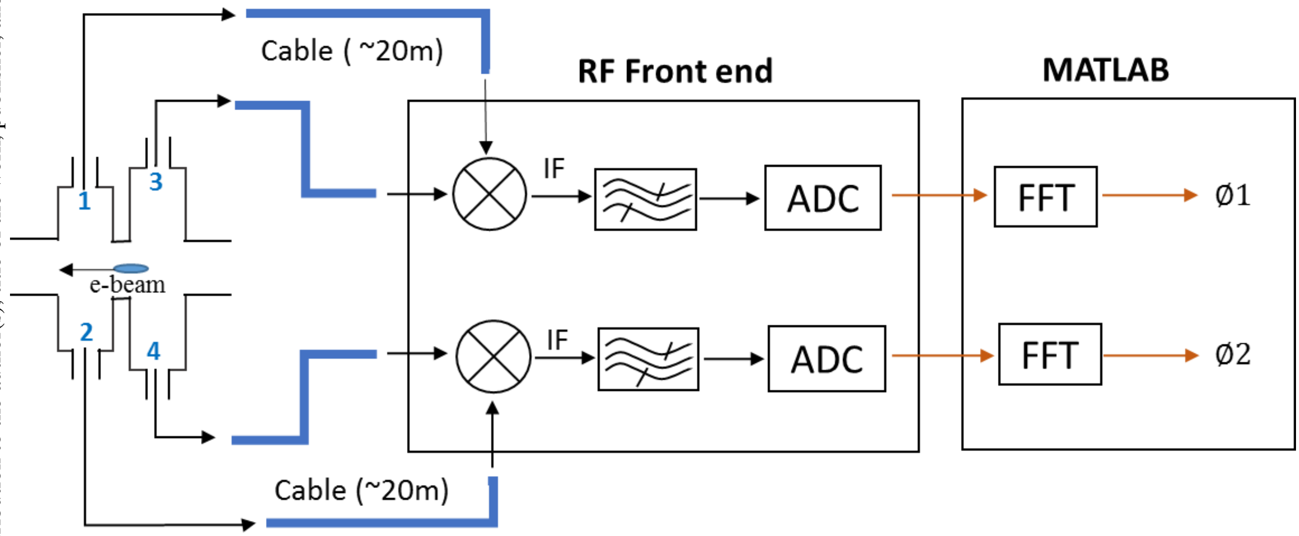


Figure 2: Schematic diagram for beam arrival time measurement.

The phases of the two IF signal can be written as:

$$\emptyset_{IF1} = \emptyset_1 + \emptyset_{noise1}$$

$$\emptyset_{IF2} = \emptyset_2 + \emptyset_{noise2}$$

Since $\emptyset_2 - \emptyset_1$ is constant, the measured resolution limitation thus mainly is system noise.

## SIGNAL PROCESS

MATLAB was used for digital IF signal processing. Figure 3 reveals the raw signal of two pickups. The two figures showed a time delay and amplitudes variation.The former is what to be measured. The later has to be considered in the down conversion section. And the delayed RF signal should be used as LO signal. Figure 4 presented the raw IF signal. Theoretically, the two IF signal should be exactly the same, however, the two port signal from the same cavities are different mainly because of manufacturing error.

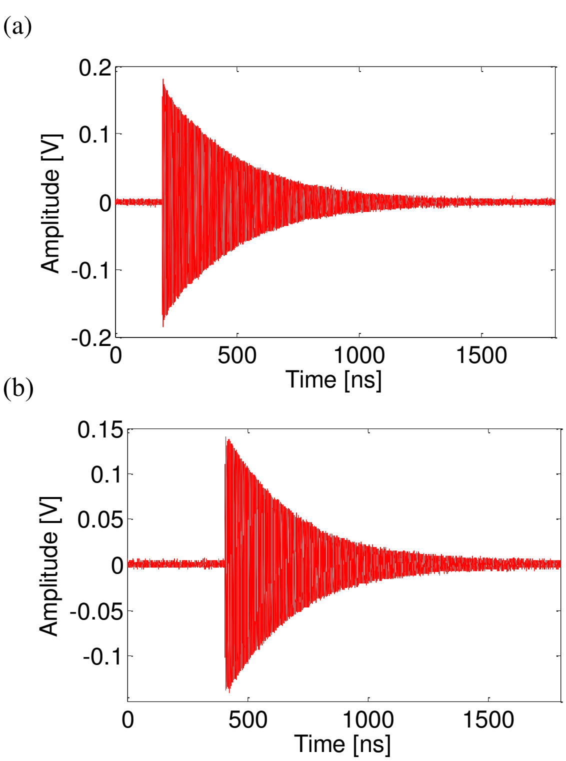


Figure 3: The raw RF signal for 200 pC bunch charge; a) port 3, b) port 1.

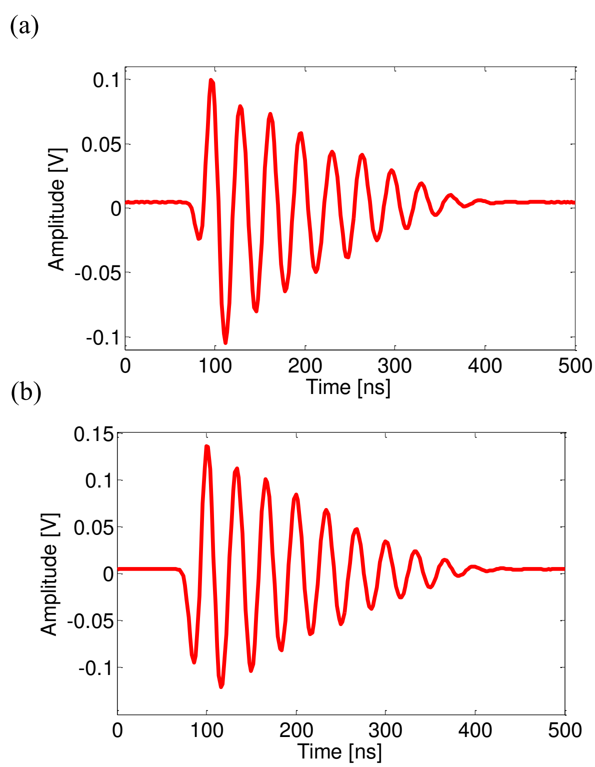


Figure 4: The raw IF signal for 200 pC bunch charge; a) port 1 and 3, b) port 2 and 4.

Although the phase of the above two IF signals are slightly different and the phase difference is about 0.004,

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the frequencies are exactly the same, which is 29.7 MHz, as shown in Fig.5.

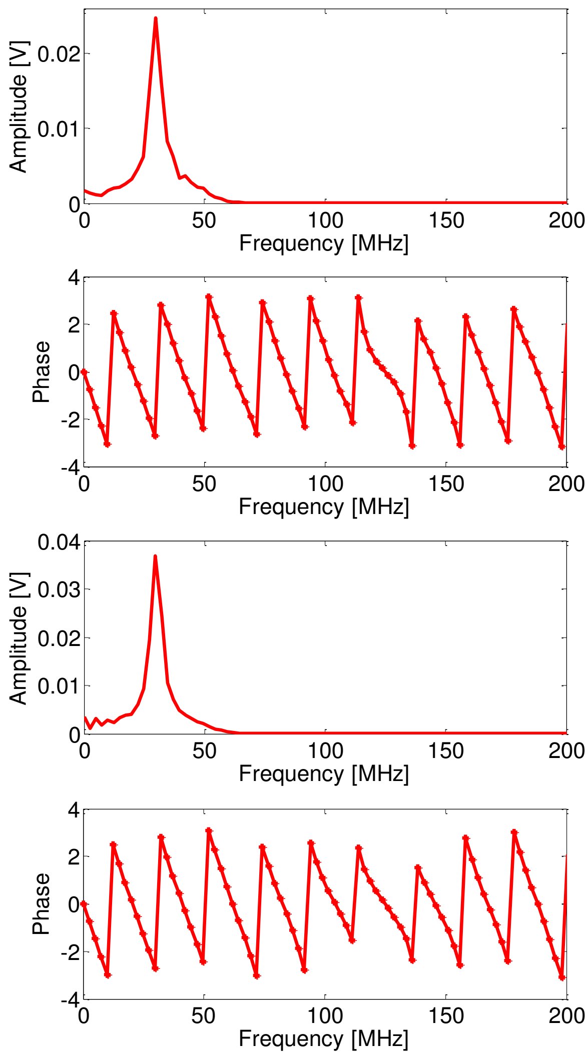


Figure 5: Magnitude spectrum and phase spectrum of two IF signal.

After 200 times measurements, the correlation plot of the two phases can be seen in Fig. 6. And it has exhibited a well linear relation. Moreover, in Fig. 7, a short-term measurement resolution of 67.7 fs can be calculated by comparing the two phase.

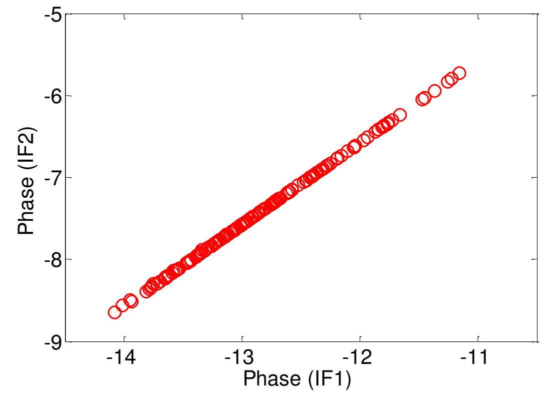


Figure 6: A correlation plot of the IF signals phase.

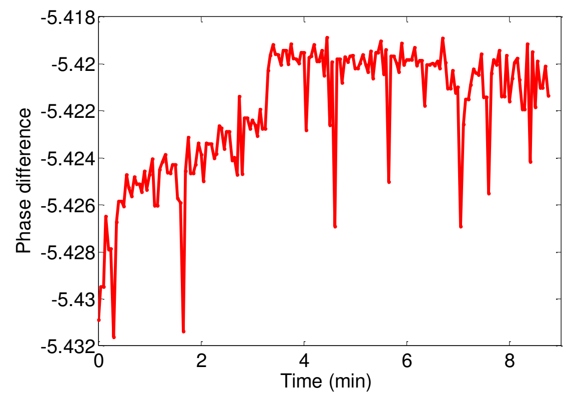


Figure 7: Short-term measurement resolution at the bunch charge of 200 pC.

## SUMMARY

In the first BAM measurement the calculated temporal resolution was 67.7 fs with dual-cavity BAM prototype. This is larger than most published results. The main limitations probably comes from the BAM electronics. The cavity manufacturing error also has an impact on the BAM resolution. Currently, the studies on the BAM electronics are ongoing. Moreover, phase-stable cables will be applied in the future experiment. Besides, there are several ideas to improve the resolution. We hope all these improvement can help the next experiment obtain better results.

## REFERENCES

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