THE APPLICATION OF DIRECT RF SAMPLING SYSTEM ON CAVITY BPM SIGNAL PROCESSING*

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Abstract

Cavity BPM signal processing system normally consists of two modules, first one is RF conditioning module(RF front end) to down convert the BPM signal to IF, second one is IF signal digitizer and digital signal processing module (DAQ) to calculate beam position and communicate with control system. The RF front end complicates the system and introduces noise. A direct RF sampling system has been constructed to process the cavity BPM signal, which structure is more concise and performance is better compared to the conventional system. The evaluation tests and an on-line RF DAQ system will be introduced in this paper.

INTRODUCTION

As the fourth-generation light source, FEL (free electron laser) is widely developed due to its outstanding performance. And in China, several FEL facilities have been built, such as DCLS (Dalian Coherent Light Source) and SXFEL (Shanghai Soft X-ray Free Electron Laser).

SXFEL is a high gain FEL. It is constructed at the bottom of 2016, now is under commissioning. The main parameters are listed in Table 1.

Table 1: SXFEL Parameters

Parameters	Value
Status	Commissioning
Wavelength	3-9 nm
Length	~300 m
FEL principle	HGHG, EEHG
Beam energy	0.84 GeV
Peak current	500 A
Normalized emittance	1 mm.mrad
Bunch length(FWHM)	1 ps
Harmonic number	30th

The improvement of FEL performance leads to higher requirement on beam-diagnose technology. Cavity beam position monitor (CBPM) is one of the important diagnostic component on FEL for its high resolution to dozens of nanometers. The output signal from CBPM is narrowband signal centralized at up to several GHz. For example, the central frequency of TM110 and TM010 signal of CBPM on SXFEL is 4.7 GHz [1], while LCLS is 11.424 GHz. This high frequency signal is hard to be sampled and processed directly limited by electronic technology. A

traditional method is to down convert the RF signal to IF signal (MHz) firstly, so that the following ADC and signal processing module (data acquisition system, DAQ) can deal with the signal.

Figure 1 is the block diagram of CBPM signal processing system on SXFEL. The front end consists of pre-amplifier in tunnel, local oscillator (LO), mixer, filters, et al. CBPM output signal is down converted to about 500 MHz after the front end. DAQ system is an in-house designed digital beam position processor (DBPM), which central frequency is 500 MHz, four channels 16 bits ADC sampling at 119 MHz [2, 3].
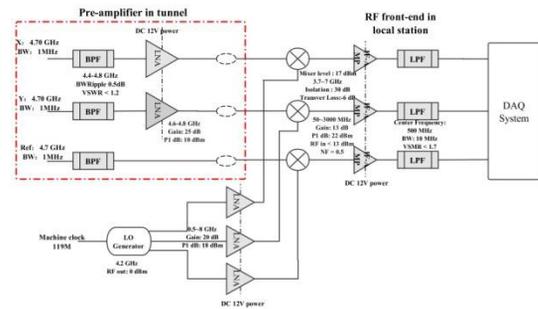

Figure 1: CBPM signal processing system on SXFEL.

This structure not only increase the costs, large numbers of RF components also make the system complex and fragile, and the components introduced extra noise will degrade the system performance. Considering this, the ideal BPM read-out electronics should contain no RF front-end [4, 5]. But this vision is infeasible in most cases, because the CBPM output signal frequency always out of the bandwidth range of most ADC. Fortunately, current electronics already enables this "ideal electronics" (6 GHz bandwidth oscilloscope) on the C band Cavity BPM system on SXFEL (4.7 GHz).

BEAM TESTS ON SXFEL

Two bunch arrival time measurement (BAM) cavities have been installed at the injection section and accelerator section to evaluate the BAM performance on SXFEL. The BAM monitor consists of two reference cavities. The central frequency of the two cavities respectively is designed to 4720 MHz and 4680 MHz. The output signal of the reference cavities can also be used to measure the bunch charge [6]. Then the BAM system can be used to evaluate the system performance by measuring the bunch charge.

RF DAQ Test

Figure 2 is the system diagram of RF direct sampling test. It consists of two BAMs in tunnel (IN-BAM01 at

injection section and LA-BAM01 at LINAC section), band-pass filters (BPF) to reject RF interference signal, a 6 GHz bandwidth oscilloscope Tektronix DPO70604. Figure 3 shows the picture of the installed BAM and the ICT that used for calibration.
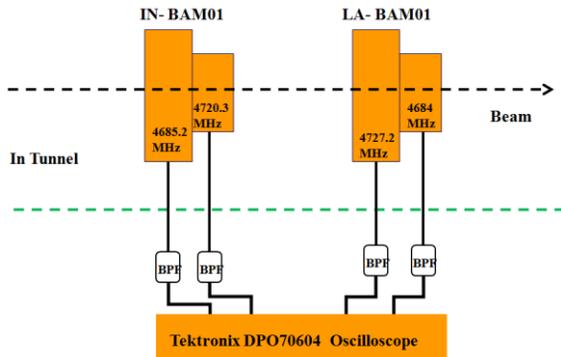

Figure 2: System diagram of RF direct sampling test.

Figure 3: The installed BAM.

The DAQ is a high performance oscilloscope Tektronix DPO70604, which is 4 channels 6 GHz bandwidth and sampling rate up to 25 GHz. A band pass filter (BPF) is used to eliminate the affection of RF signal. The bunch charge is get from the peak value of calculated FFT amplitude, and calibrated with ICT.

The relative charge resolution of IN-BAM01 and LA-BAM01 were shown in Fig. 4 and Fig. 5. The results show that the relative resolutions of the two monitors are better than 0.3%.
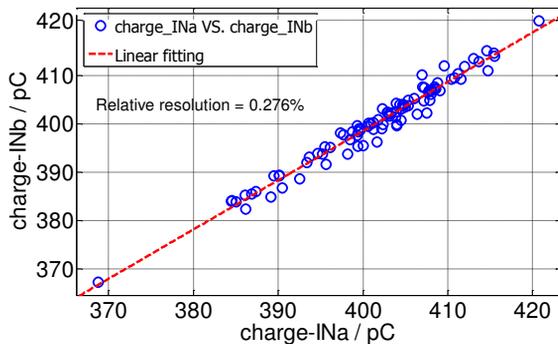

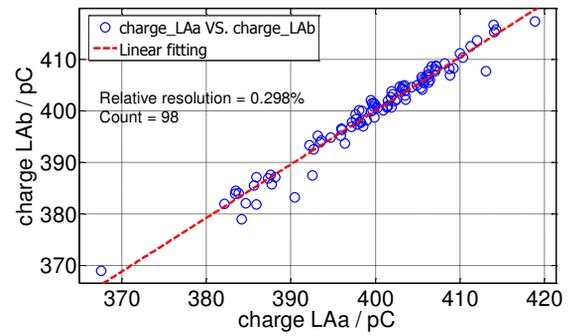Figure 4: Resolution of direct sampling IN-BAM01.

Figure 5: Resolution of direct sampling LA-BAM01.

Traditional DAQ test

At the same time, a traditional down-converting DAQ system has been constructed for comparison. Except for BPF and oscilloscope, the system contains LO generator which can generate a sinusoidal signal with a frequency of 4706 MHz and an amplitude of 17 dBm, a mixer to down-convert the RF signal by LO signal, a LPF removes the high frequency signal and out of band noise. The system diagram can be seen in Fig. 6, and Fig. 7 is the field picture of the system.
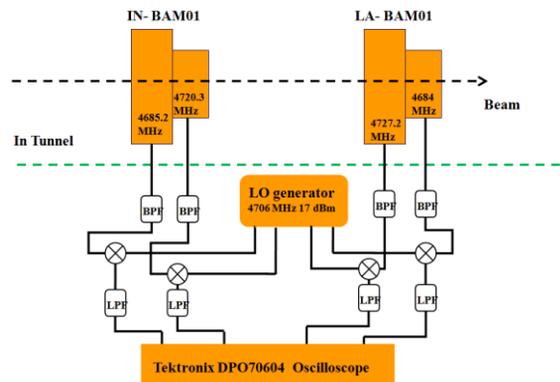

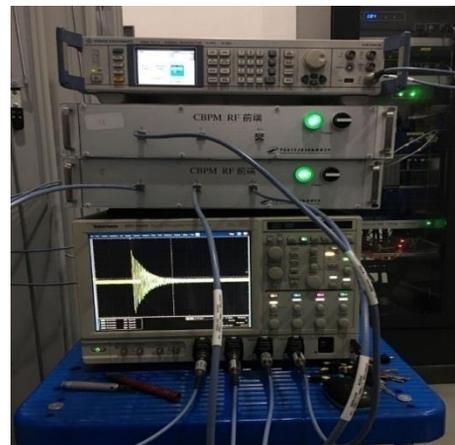Figure 6: System diagram of traditional down-converting DAQ system.

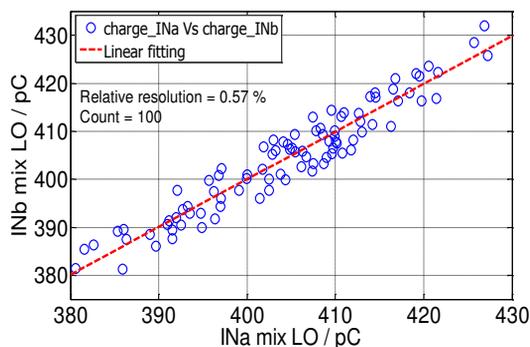Figure 7: The field picture of experiment platform.

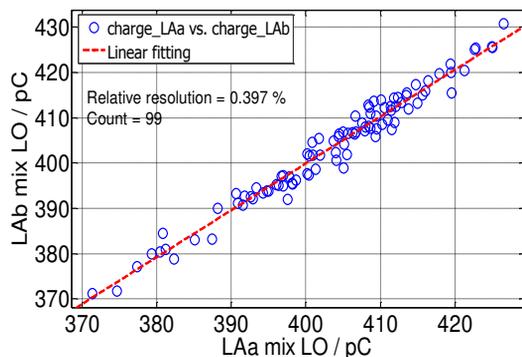Figure 8: Resolution of down-convert sampling IN-BAM01.

Figure 9: Resolution of down-convert sampling LA-BAM01.

The test results in Fig. 8 and Fig. 9 show that relative resolution of the two monitors is about 0.6% and 0.4% respectively. Obviously the performance is worse than direction sampling DAQ system. The reason is the down-converting components introduced noise. The relative resolution is about 0.3% while the ADC of DPO70604 is 8 bits, we can expect it should be better than 0.1% after applying 12 bits ADC.

NEXT STEP: ON-LINE RF DAQ SYSTEM

With the rapid development of analog-to-digital conversion technology, an on-line RF direct sampling equipment with high bits and high bandwidth is not out of reach. Figure 10 is a demo board EV12AD500A from company E2V. It contains a dual channel 12 bits ADC, which input bandwidth is ultra-high to 5.2 GHz and the sampling rate up to 1.5 GSps. Figure 11 is the corresponding connectivity board VC709 from XILINX. It contains a Virtex-7 FPGA XC7VX690T, dual DDR3 small outline dual-inline memory module (SODIMM) memories, an 8-lane PCI Express interface, etc. Combing with the two boards, an on-line direct RF sampling DAQ system can be built to process CBPM signal. The system is not ready yet, the progress will be introduced in the future.

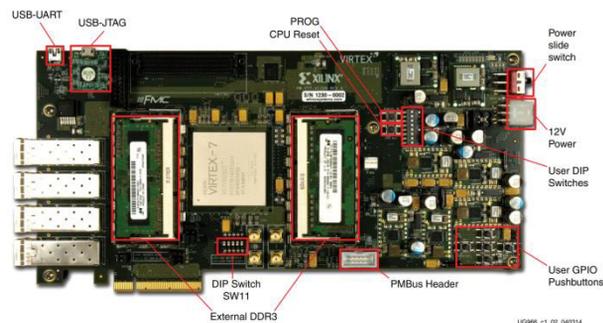Figure 10: ADC demo board EV12AD500A.

Figure 11: XILINX VC709 FPGA board.

CONCLUSION

The tests shown that the relative resolution of direct RF sampling DAQ is obviously better than traditional down-converting structure. In the next stage, an on-line RF DAQ system will be constructed with commercial boards.

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