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DEVELOPMENT OF BAM ELECTRONICS IN PAL-XFEL

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Abstract

We describe the electronics for electron bunch arrival time monitor (BAM) with a less than 10 femtosecond resolution, which was developed in 2017 and is currently in use at PAL-XFEL. When electron bunches go through an S-band monopole cavity, about 1 us long RF signal can be obtained to compare with a low phase noise RF reference. The differential phase jitter corresponds to the arrival time jitter of electron bunches. RF front-end (F/E) which converts the S-band pickup signal to intermediate frequency (IF) signal, is the essential part of a good time resolution. The digitizer and the signal processor of the BAM electronics are installed in an MTCA platform. This paper presents the design scheme, test results of the BAM electronics and future improvement plans.

INTRODUCTION

In the tunnel of PAL-XFEL, 10 BAM pickups are installed. The pickup is made of S-band monopole cavity type. The resonance frequency is 2826 MHz, which have the offset of ≈30 MHz from our reference, 2856 MHz to remove a dark contribution. More details on the BAM pickup are described in Ref. [1].

BAM electronics consists of RF F/E unit for the frequency conversion of the pickup signal to an IF signal and main IOC for digitizing and processing the signal. RF F/E was designed as non-platform type (e.g. pizza-box type) and main IOC was implemented on the MTCA.4 platform.

The prototype of the BAM electronics, which is developed in 2017, has been tested at both the injector and the main-dump sites.

Table 1 shows the main specifications of the BAM electronics.

Table 1: Specification of the BAM Electronics

Parameter	Value	Unit
Phase Measurement Resolution	≤ 10	fs
Repetition Rate for Operation	≥ 60	Hz
Input RF Frequency	2826	MHz
REF Frequency	2856	MHz
Sampling Frequency	238	MHz
Platform	MTCA.4	

ELECTRONICS

The block diagram of the BAM electronics is shown in Fig. 1.

The signals induced from the pickup are transmitted to the RF F/E via cables with good phase stability for temperature. The BAM pickup signals are converted to IF signals of about 30 MHz using a mixer.

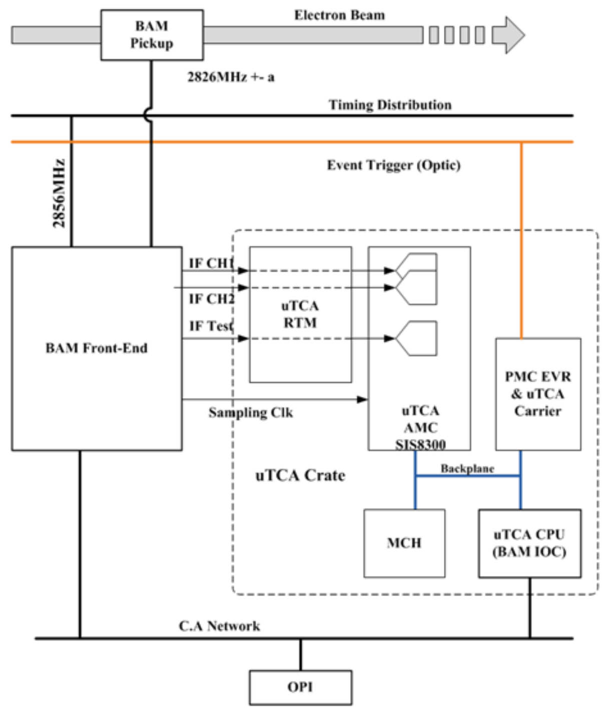

Figure 1: BAM electronics block diagram.

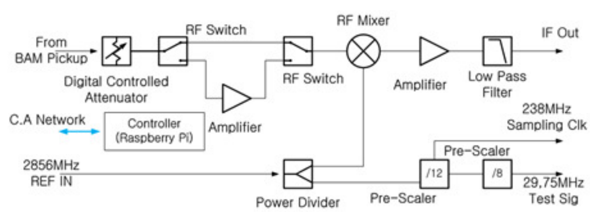

Figure 2: Block diagram of the RF F/E.

Figure 2 shows the RF F/E block diagram. A digital con-trolled attenuator is installed at the input, and is followed by a switch bank. In a high charge mode, the switch is bypassed and in a low charge mode, the signal is passed through the amplifier for power matching. The frequency down-converted signal using the reference in the mixer go through the IF amplifier and the low pass filter [2].

For the digitizer, a synchronized 238 MHz sampling clock, the 12th sub-harmonic of the reference, is generated in the RF F/E. The jitter of the sampling signal has to be small because it affects the signal noise ratio (SNR) of the system. We used HMC905LP3E and HMC794LP3E pre-scaler chips from Analog Device Inc. The total jitter of the 238 MHz sampling clock measured using a signal-

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analyzer is about 16 fs. Table 2 below shows the phase noise value at each offset frequency.

Table 2: Phase Noise of the Sampling Clock

Phase Noise	Offset
-115 dBc/Hz	100 Hz
-143 dBc/Hz	1 KHz
-155 dBc/Hz	10 KHz
-160 dBc/Hz	100 KHz
-163 dBc/Hz	1 MHz

Figure 3 shows the installation of the BAM electronics. The upper crate is the main IOC, MTCA crate, which is equipped with a digitizer and a processor cards. There are five digitizer cards. The most rightward one is for BAM and the remaining four digitizers are for beam position monitors (BPMs). To reduce costs, BAM and BPM electronics share the whole system except the digitizer.

Figure 3: Photograph of the BAM Electronics; MTCA Crate on the top and RF F/E on the bottom.

DIGITAL SIGNAL PROCESSING

The block diagram shown in Fig. 4 illustrates the basic concept of phase processing. A digital down-converter (DDC) generates complex samples by multiplying the digitized IF signal from the ADC with a generated cosine and sine signals from a numerically controlled oscillator (NCO). The SIG_I and SIG_Q signals can then be filtered to remove unwanted frequency components (especially the sum frequency component). The digital filter type is a 16-Tap FIR filter. MATLAB Filter Design & Analysis Tool program was used to calculate the filter coefficients.

When the frequency of the NCO is equal to the frequency of the IF, the difference frequency component at the output of the multiplier becomes zero, and only the amplitude component of the I-Q signal remains. The phase can be calculated by the equation arc-tangent [Q/I] function. More detail of the calculation process is described in Ref. [1].

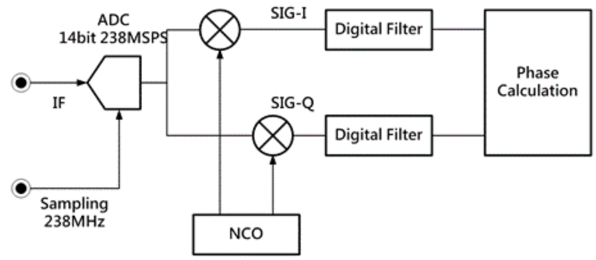

Figure 4: Data processing flow.

The resolution of BAM electronics is closely related to the SNR of the system. Figure 5 shows the simulation result of the relationship between SNR and the BAM phase resolution. The target specification of the prototype was less than 10 fs, and for this, the SNR of the electronics should be at least better than 65 dB [3].

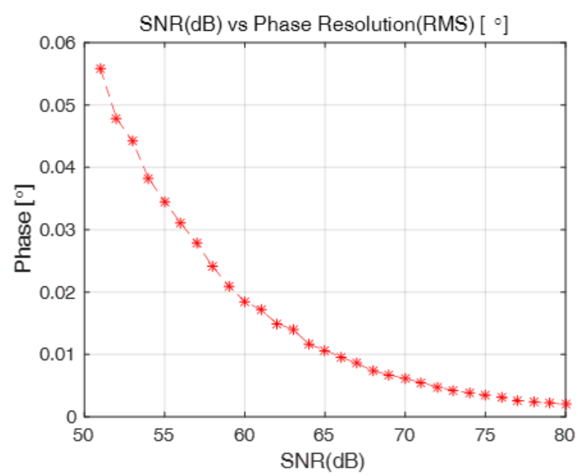

Figure 5: Simulated BAM resolution estimation with the SNR.

Table 3: RF F/E and ADC Gain & NF

Component	Gain (dB)	NF (dB)
Injector site Cable Loss	-3.5	3.5
Controlled Attenuator	Controlled	Controlled
RF SW1	-1.5	1.5
RF SW2	-1.5	1.5
Mixer	-9.0	9.0
Amp	18.0	5
Filter	-0.3	0.3
ADC	0	28.87

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Table 3 shows the gain and noise figure (NF) of the RF F/E and the ADC. The SNR is calculated based on this.

The ADC used in the SIS8300-LX50 is AD9643-250 and according to the datasheet, the SNR is typical 72 dB for the IF 30 MHz, VIN -1 dBFS and sampling 250 MSPS. Based on these conditions, NF value of the ADC is 28.87 dB for the Nyquist-Bandwidth [4, 5].

Although the NF varies with the value of the controlled attenuator, the SNR of the electronics remains almost constant value of 71 dB at the high charge (100 pC or more) conditions. This is because when the attenuator is adjusted according to the magnitude of the pickup power, the change of the NF due to the adjustment of attenuator is almost equal to the change of the pickup power.

ADC jitter is also an important factor affecting SNR.

$$t_{jitter} = \sqrt{(t_{jitter.sampling})^2 + (t_{jitter.Aperture\ ADC})^2}$$

$$SNR_{jitter}[dBc] = -20 \cdot log_{10}(2\pi \cdot f_{IN} \cdot t_{jitter})$$

The total jitter of the 238 MHz sampling clock is about 16 fs and the aperture jitter of the ADC is typical 0.1 ps according to the datasheet. SNR due to jitter is more than 90 dB at 30 MHz IF [6]. Therefore it is considered that the jitter does not affect the system SNR.

Since the SNR of the electronics is 71 dB, electronics seems to meet the resolution performance of less than 10 fs.

TEST RESULT

Figure 6 shows the correlation of phase between BAM channel-1 and channel-2 measured on the injector site for one hour.

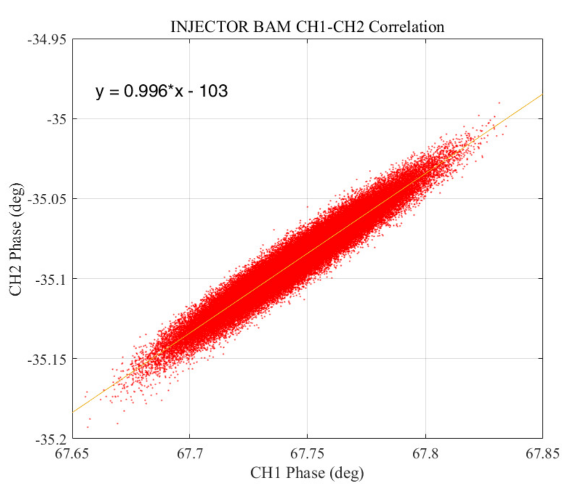

Figure 6: Correlation of phase between two channels measured on the injector site.

The BAM output phases are from two different ports of the same pickup cavity and processed independently. Since the measurement value of each channel includes the jitter from the electron beam arrival time, the resolution of only electronics can be obtained by the difference in the phase values obtained by operating on each channel for the same electron bunch.

Figure 7 shows the resolution measurement results of the electronics itself with the elimination of the jitter component of the electron bunch. These values represent the standard deviation value for 100 pulses of the difference between channel-1 and channel-2. The average jitter was about 5.8 fs.

Figure 8 shows the phase variation of the electronics for 2.5 days. RF F/E generates a 29.75 MHz continuous wave signal, which is used as a debugging signal, and an input to the extra digitizer channel. We can see that there was a phase change of about 0.06 degrees for 2.5 days.

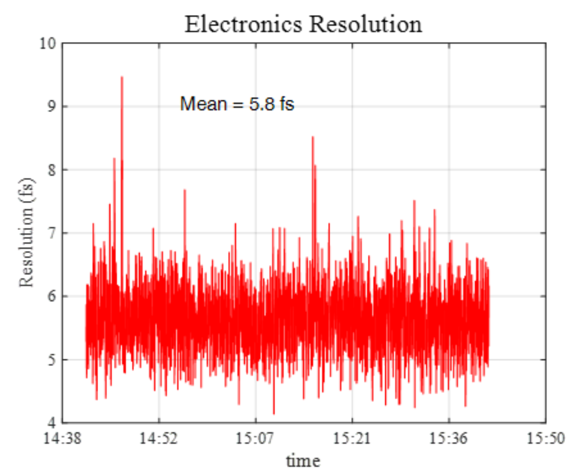

Figure 7: BAM electronics resolution over 100 pulses for 1 hour at 200 pC.

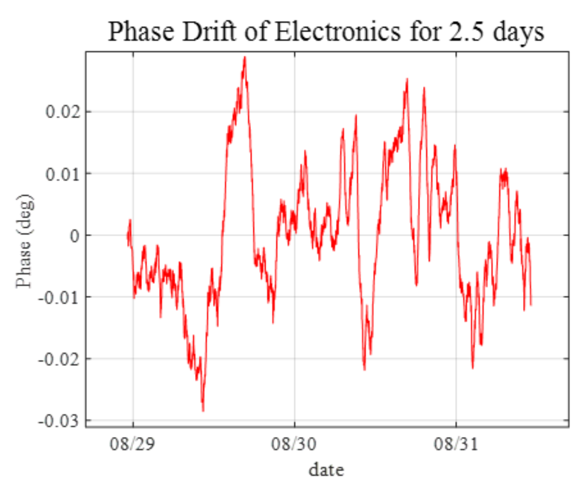

Figure 8: Phase drift of the electronics for 2.5 days.

SUMMARY

BAM electronics satisfied the goal 10 fs resolution performance and showed similar characteristics to the simulation results.

Based on the above design, one additional electronics will be built in 2019 and will be installed in the injector and the hard X-ray main dump site.

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On the other hand, there is a phase drift problem due to the temperature change. We are trying to improve this problem through feedback control.

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