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DESIGN OF STRIPLINE BPM FOR THE SHINE PROJECT*

T. Wu[1], Y.B. Leng†, L.W. Lai, S.S. Cao, J. Chen, B. Gao, Y.M. Zhou
Shanghai Institute of Applied Physics, Chinese Academy of Science, Shanghai, China
also at University of the Chinese Academy of Science, 100049 Beijing, China

Abstract

As an under-constrution fourth-generation light source in China, SHINE (Shanghai HIgh repetition rate XFEL aNd Extreme light facility) is expected to play an important role in basic scientific research in the field of materials and medicine. However, the performance of FEL depends critically on the completeness and quality of their beam diagnostic systems. Since the SHINE project will operate with bunch charge at 100pC, which is only one-quarter of that in the SXFEL, the measurement accuracy requirements for SBPM will increase significantly. On the other hand, the bunch repetition frequency of SHINE reached 1MHz, which shortened the threshold for measuring dead time. Fitting the requirement, the passband and the sampling rate design of stripline BPM is upgraded for the SHINE project.The final design was simulated using the data on the SXFEL, and the some inspiring results have been made.

INTRODUCTION

SHINE project has entered the construction since 2018 and will be completed and put into use in 2025 as planned. SHINE can provide high-frequency lasers in the hard X-RAY band after it is built, and is expected to play an important role in basic scientific research. As an important part of SHINE, the beam diagnostic system can help to improve the stability of SHINE operation, improve device performance and provide maintenance and provide reference for accelerator engineers to maintain and optimize. SBPM is one of the widely used measuring devices in beam diagnostic system.

Stripline BPM is planned to be installed at the injector section and the low energy room temperature section of linear accelerator, mainly for accurate transverse position measurement and auxiliary bunch charge measurement. According to the design specifications, it is required that the accurate measurement of bunch-by-bunch (repetition rate 1MHz) parameters be realized under the design operating charge (100pC), and that the measurement can also be carried out under the low charge condition (10pC). While satisfying the above functions, we must ensure that the whole acquisition system is implemented within the framework of EPICS.

The overall design of SBPM draws lessons from the mature schemes of similar devices on SCLF, but each index is higher, which requires further optimization of the parameters selection and design of SBPM to improve the overall performance of data acquisition system. In this paper, based on SCLF, the design of SBPM on SHINE will be optimized through data simulation and experimental verification.

SYSTEM STRUCTURE

The design of SBPM in SHINE will largely follow the similar design in SCLF, which means that the center frequency of the signal to be tested will still be around 500MHz, and its spectrum is as shown in Fig. 1 [1].

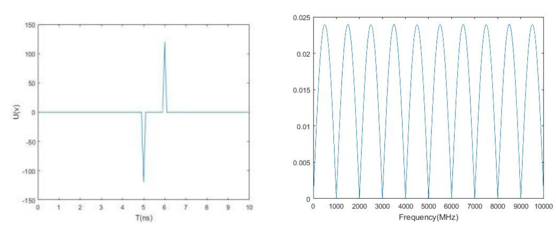

Figure 1: SBPM output signal(left) and the spectrum.

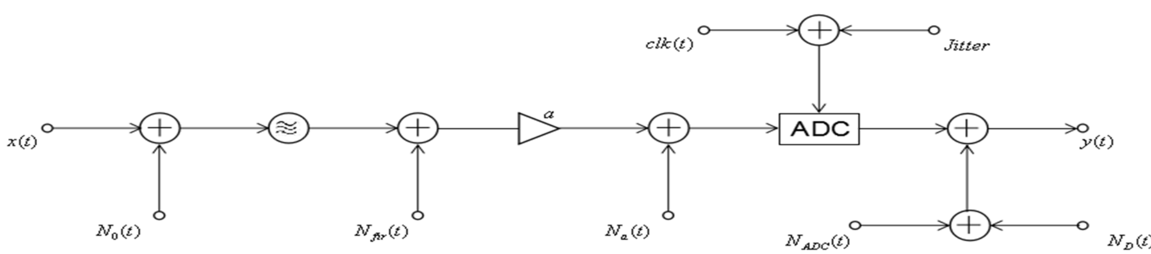

Figure 2: the signal flow graph of Stripline BPM.

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† lengyongbin@sinap.ac.cn

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The signal flow diagram of Stripline BPM is shown in Fig. 2. The signal measured by the physical probe first passes through the filter and amplifier. The output signal will be analog-to-digital converted by the ADC and input to the FPGA for further data processing. The noise introduced during the processing of digital signals is small and negligible, so the noise of the SBPM measurement system mainly comes from the stage shown in Fig. 2. Noise mainly includes noise introduced by the device (amplifier, filter, ADC) itself, noise introduced by ADC clock jitter, and ADC quantization noise.

SIGNAL PROCESSING

Processing Method Selection

FFT (Fast Fourier Transformation) and acquisition maximum are two of the more common methods used in Stripline BPM data processing. The FFT method is more common, and Stripline BPM data processing in SCLF also uses this design. By performing FFT on the signal measured over a time, a spectrogram of the signal can be obtained and the power of the signal can be calculated. As the data collected by a single measurement is more, the anti-interference ability of the FFT method is stronger. The method of acquisition maximum is very dependent on the ideal measurement system, but it can maximize the performance of ADC. The processing method discussed in this article is primarily FFT [2].

Influence of Difference Over Sum Method

The signal measured by the probe contains both the position information and the charge information of the bunch. The Difference over sum method is used to eliminate the influence of the charge amount of the bunch. As can be seen from the following proof process, when the beam is near the equilibrium position, the error of the measured signal is similar to the difference over sum result error.

SIMULATION EXPERIMENT

Influence of Filter Passband

The influence mainly comes from amplifiers. With the increase of the bandwidth of the filter, the signal duration will be shortened while the maximum value will increase, just as what is showed in Fig. 3. In order to maximize the use of ADC, the gain of the amplifier will change accordingly, ensuring that the maximum output signal of the amplifier remains unchanged. The change of amplifier gain will affect the signal-to-noise ratio of Stripline BPM system [3].

The curve is shown in the Figure 4. It can be seen that with the widening of the filter passband, the noise introduced by the filter generally decreases and tends to be stable. The reason is that the thermal noise increases

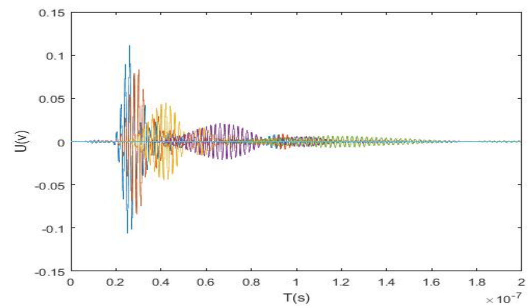

Figure 3: Waveform under different passband.

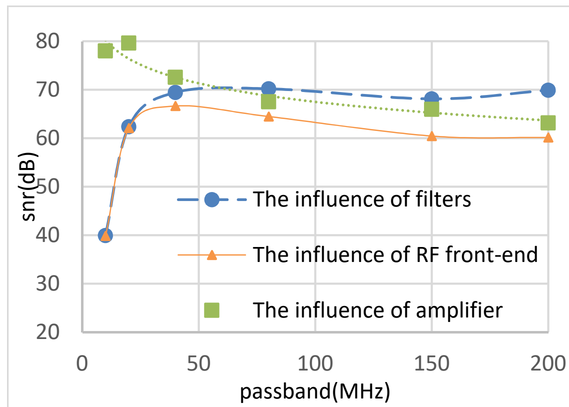

Figure 4: The influence of filter passband.

slowly as the input signal power increases near the center frequency, while the input signal power increases slower as it moves away from the center frequency.

Since the maximum is controlled to be the optimal range of ADC, the power of the output signal of the filter decreases with the increase of the filter passband after the amplifier, and the noise of the amplifier increases with a small amplitude, which makes the noise influence of the amplifier increase with the widening of the filter passband in general.

Influence of ADC

The effect of ADC is shown in Figs. 5-7. It can be seen that the influence of quantization noise introduced by ADC is similar to that introduced by amplifier, and its influence trend is the same. On the other hand, with the increase of ADC effective digits, the overall signal-to-noise ratio of the acquisition system increases and tends to be stable.

The influence of ADC sampling rate on SNR is very limited, which may be due to the fact that only the signal power is meaningful in the process of SBPM measurement.

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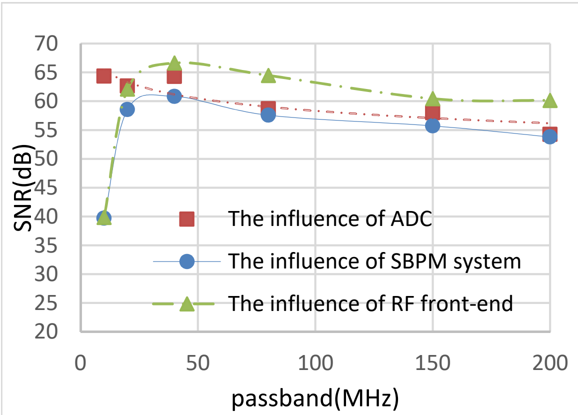

Figure 5: The effect of ADC in different passband.

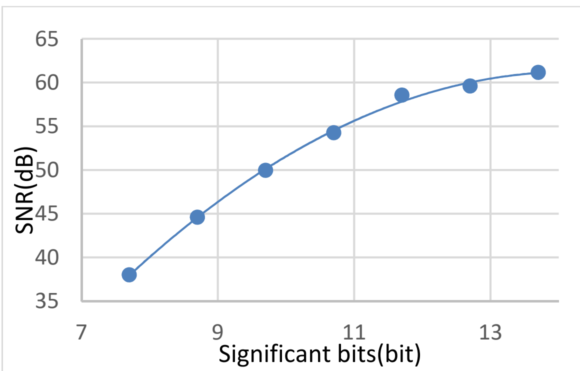

Figure 6: The effect of ADC Significant bits.

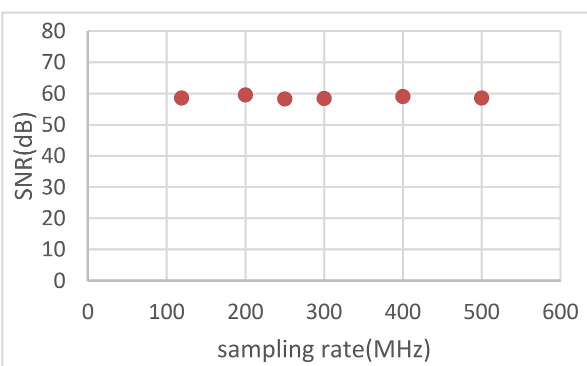

Figure 7: The influence of ADC sampling rate.

Influence of Time Shake

A slight clock disturbance can have a huge impact, so that it completely exceeds the influence of other factors. However, the clock accuracy requirements should be as high as possible during the construction of the SHINE project.

CONCLUSION

According to the results of simulation experiments, the selection range of technical parameters of Stripline BPM measurement system in SHINE has been given. It should be noted that the performance indicators and installation environment of specific devices will still affect the trend of the influence of different parameters on the signal-to-noise ratio of the system, which makes the design of SBPM still pending before complete completion.

However, through simulation experiments, the influence of different parameters on SBPM performance has been clear, which means that in the next research process, we can focus more on important parameters, such as filter passband and clock jitter. Finding parameters that have little influence on the accuracy of SBPM system can also help us simplify the design and shorten the construction period.

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