

DEVELOPMENT OF THE SIMULATION SOFTWARE PACKAGE FOR THE CBPM SYSTEM *

J. Chen, Y.B. Leng[†], L.Y. Yu, L.W. Lai, N. Zhang, SSRF, SINAP, Shanghai, China

Abstract

In recent years, the development and construction of Free Electron Laser (FEL) facilities are in full swing. For FEL facilities, to generate coherent X-ray, cavity beam position monitor (CBPM) system which consist of cavity BPM, RF front-end and signal processor are employed to measure the transverse position in the undulator section. A generic simulation software package, with the S_{21} parameters of the real components, for the design of the RF front-end and optimize the CBPM system was developed. In this paper, the development of the generic simulation software package and the experiment results with beam at Shanghai Deep ultraviolet (SDUV) FEL facility to verify the correctness of the simulation soft package will be introduced. The application in the design and optimize of the RF front-end for the Dalian Coherent Source (DCLS) will be addressed as well.

INTRODUCTION

The Free Electron Laser (FEL) laser based on linear accelerator, known as the fourth generator light source, has a higher brightness, ultrafast time resolution and has characteristics such as full coherent compared with the synchrotron radiation source. In the field of scientific research, to meet the growing demands of the biological, chemical and material science research, an increasing number of FEL user facilities have been constructed and being proposed in the world.

But for FEL facility, the measurement and control of the beam position are the critical elements which need to keep electron beam and generated photo beam overlapped in the undulator section for sufficient FEL interaction. The requirement of the beam position resolution is generally less than 1 μm . Cavity beam position monitor adopt a resonant cavity structure and through the use of antisymmetric characteristic modes, coupled from the cavity, to measure the beam position which can meet the requirement. So the cavity BPM is widely used in FEL facilities and a variety of large hadron collider [1].

Cavity BPM system is consists of cavity probe, radio frequency (RF) front-end and data acquisition system:

1. A cavity probe includes a position cavity and a reference cavity which can extract the information of beam position and beam charge.
2. RF front-end filters, amplifiers the RF signal extracted from the cavity probe and down-converts them to an appropriate intermediate frequency (IF).
3. Data acquisition system digitized the IF signal and then processed on line or offline so as to get the information of beam position.

*Work supported by National Natural Science Foundation of China (No.11575282)

[†]lengyongbing@sinap.ac.cn

For the design of the RF front-end which need to base on the characteristics of the cavity probe to select components and match with the performance of the data acquisition system so as to get a better result. But in most cases, people are using model library of the Advanced Design System (ADS) to do the relevant simulation or direct calculation. In this case, the progress may be more complex and cannot show the amplitude and frequency response of the component within the entire signal bandwidth, so the simulation results may also have a greater deviation to the actual selection of the device.

In this paper, we proposed a method which using scattering parameters of the real component combine with the signal data of the cavity probe to simulate the result when signal through the component. It has an advantage of closing to the actual component performance. A generic simulation package for the design of the RF front-end is also developed based on this method.

PRINCIPLE OF THE SIMULATION

In the field of electrical engineering, the introduction of single-port network and multi-port network model has many advantages in simplifying complex circuits and in studying the characteristics of active and passive devices. It is possible to determine the input and output characteristics of the network by experiment without having to understand the internal structure of the system. Scattering parameters (S parameters) are the most common method which using the incident power wave and to reflect the power wave to define the input and output relationship of the network[2]. Figure 1 illustrate the block diagram of the S parameters for two-port network, the S parameters can also be expressed by Eq. (1):

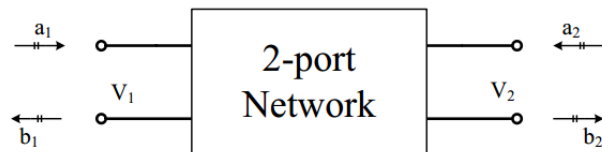


Figure 1: Definition of S-parameters for two-port network.

$$\begin{bmatrix} b_1 \\ b_2 \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \end{bmatrix} \quad (1)$$

The response of RF component to signal is manifested as a change in amplitude and phase. When the signal passes through the RF component, the response of the component to the signal's amplitude in the frequency domain is expressed as a gain or insertion loss at the corresponding frequency, to the signal's phase is expressed as a phase delay. Combing with the signal and amplitude-

frequency, phase-frequency response of the RF component, the effects of the signal through the components can be expressed by Eq. (2):

$$f = A_1 e^{i\phi_1} * A_2 e^{i\phi_2} = A_1 A_2 * e^{i(\phi_1 + \phi_2)}. \quad (2)$$

Where the A_1 , ϕ_1 are the amplitude and phase of signal that can be get by the Fast Fourier Transform (FFT). The A_2 , ϕ_2 are the amplitude-frequency and phase-frequency response function of the RF component which listed in S_{21} parameters that can be get by the network analyzer or supplier.

ESTABLISHMENT OF THE SIMULATION PLATFORM

We use *MATLAB* to establish the simulation platform. The simulation process is mainly composed of two parts, pre-processing module and main program module. Due to the processing object of the *MATLAB* is the form of matrix, so the role of the pre-processing module is to deal with the S-parameters we obtained and make it consistent with the dimensions and the form of the signal data to be processed. The specific process can be summarized as following parts:

1. Import the frequency, insertion loss and phase information of the S_{21} parameters to workspace.
2. Extended or cut the above information to the same frequency bandwidth of the signal to be processed.
3. Linear interpolation is performed for frequency, insertion loss and phase information of the S_{21} parameters of the RF-component which need to have the same dimension as the signal data. But it is important to note that the phase needs to be unwrapped before interpolated.
4. Since the amplitude-frequency curve of the signal is symmetrical about $F_s/2$ and the phase-frequency curve is centro-symmetric about $F_s/2$ after FFT, so the amplitude-frequency and phase-frequency response curve of the S_{21} parameters also do the same treatments.
5. Finally, the amplitude-frequency and phase-frequency data obtained by the pre-processing are combined into a plural form so as to express the response of the signal through the RF-component by the Eq. (2).

Figure 2 shows an example of a cavity BPF, expressing the process of pre-process after measured the S_{21} parameters by the network analyzer.

The role of the main program module is to use Eq. (2) to express the response of the signal through the RF-component by the pre-processed data. And the design diagram of the RF front-end can be interpreted as a signal through various components in succession. The time domain waveform can also be obtained by using the method of Inverse FFT (IFFT). A generic simulation software package including a Graphical User Interface (GUI) has been developed which was shown in Fig. 3.

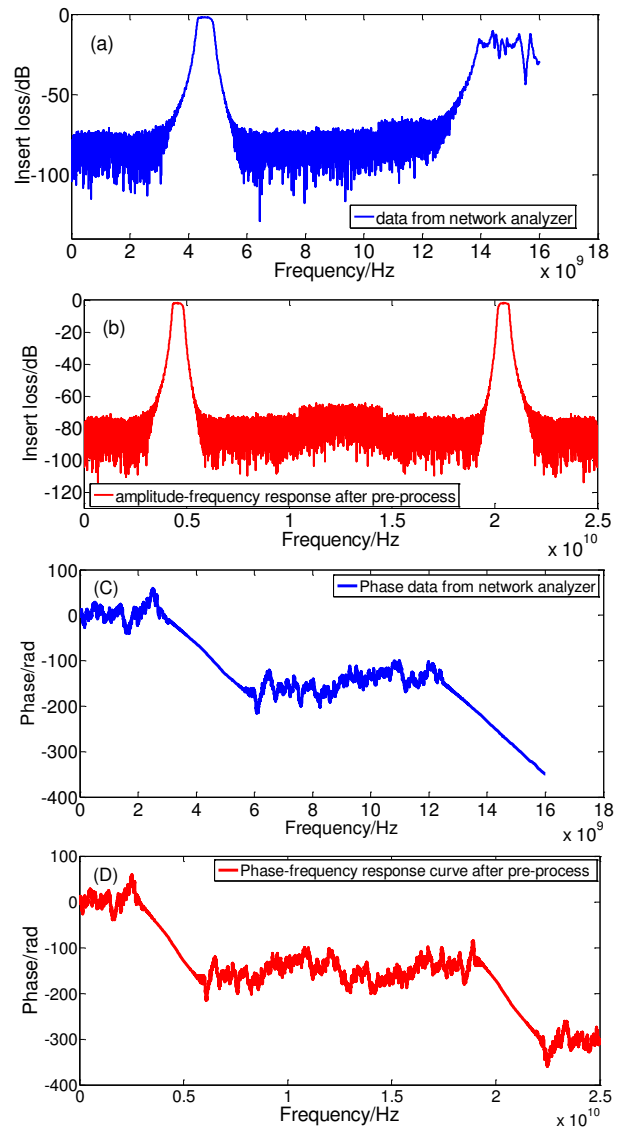


Figure 2: S_{21} parameters data of a cavity BPF. (a) amplitude-frequency response curve measured by network analyzer. (b) amplitude-frequency response curve after pre-processed. (c) phase-frequency response curve measured by network analyzer. (d) phase-frequency response curve after pre-processed.

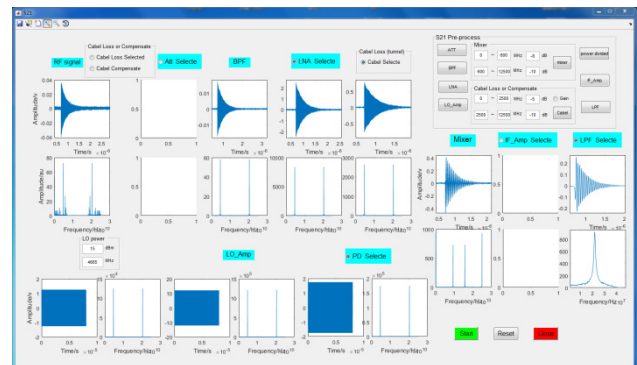


Figure 3: GUI of the generic simulation package

VALID VERIFICATION BASE ON THE EXPERIMENT DATA

To verify the availability of this method and the soft-package, the experiment data (based on the SDUV facility)[3] obtained at each component node was compared with the simulation results. Figure 4(a) illustrate the waveform, acquired by the broad-bandwidth oscilloscopr, that the RF signal extracted by the high Q cavity pass through the BPF. Figure 4(b) show the simulation results based on the method we proposed. It can be found that the simulation results matched well with the experiment data.

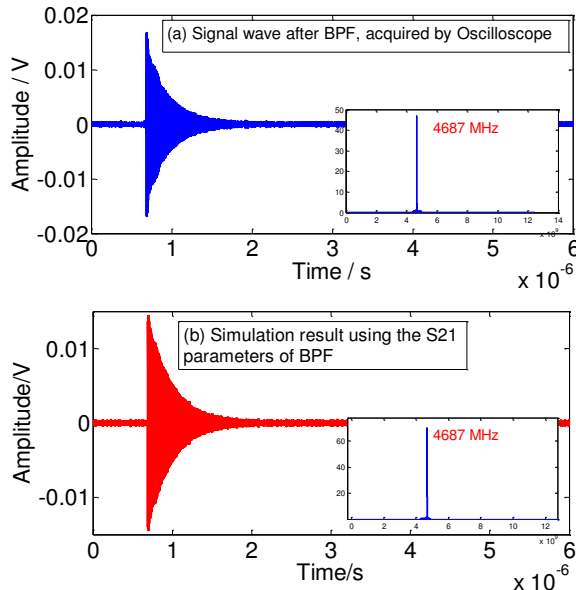


Figure 4: Comparison of the simulation results with the experiment data.

APPLICATION OF THE SIMULATION PACKAGE

Using this method and simulation package, combined with the original waveform data coupled from the cavity BPM of the DCLS facility, the design and optimization of the RF front-end has been finished. The simplified block diagram is illustrated in Fig. 5.

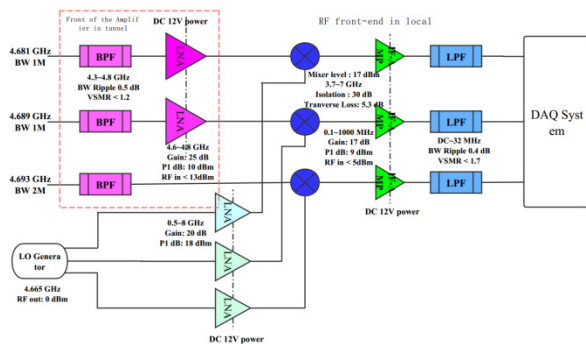


Figure 5: Design and optimization of the RF front-end based on the simulation package.

In addition, the simulation combined with the parameters of ADC provided a tool to simulate the limitation of beam position resolution for the CBPM system. As shown

in Fig. 6, the limitation of the beam position resolution for the CBPM system that has been built on DCLS (Dalian Coherent Light Source) was simulated, about 350 nm (the red line), which is consistent with the results obtained by the beam test.

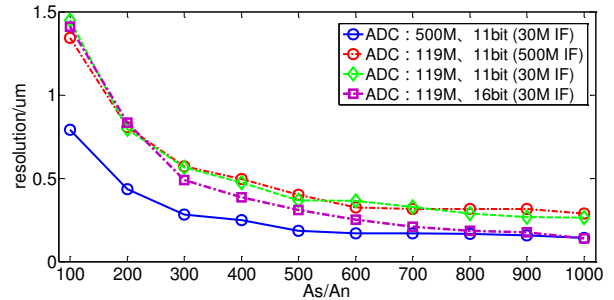


Figure 6: To evaluate the beam position resolution of the CBPM system using the simulation tool.

CONCLUSION

The design principles of the simulation package which devoted to the design of the RF front-end and the optimize of the CBPM system was described. The amplitude and phase information of the original signal are processed using the S_{21} parameters of the real RF component in the frequency domain to express the response of them, and it can also transform to the time domain through the method of IFFT. A simulation platform was established based on the *Matlab* and the advantages were shown that:

1. The signal data from the cavity, MIFIA or CST can be combined with the S parameters of the RF component to simulate the selection of the RF component to simulate the selection of the RF component, it will be more closed to the actual results.
2. For the design process of the RF front-end, only need to import the S parameters of the selected component and we will know the status of the signal pass through the component, without complex calculations.
3. More convenient, intuitive and can reduce the waste of resources.

At present, the simulation package achieved the function of the design for the RF front-end and the simulation of the resolution for CBPM system basically. But in the process of packaging is not perfect and we hope to improve this package in the follow-up work.

REFERENCES

- [1] T. Slaton *et al.*, “Development of nanometer resolution C-band radio frequency beam position monitors in the final focus test beam”, in *Proc. LINAC’98*, Chicago, USA, August 1998, paper TH4064, pp. 911-913.
- [2] Andrei Grebennikov, “RF and Microwave Power Amplifier Design”. Cambridge, USA: Publishing House of Electronics Industry, 2006.
- [3] Jian Chen *et al.*, “Beam Test Results of High Q CBPM prototype for SXFEL”, *Nuclear Science and Techniques.*, vol. 28, pp. 51(1-8), 2017.