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A HIGH VOLTAGE FEEDFORWARD SUBSYSTEM OF LOW LEVEL RF SYSTEM FOR THE HIGH POWER RF SYSTEM

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Abstract

The Low Level Radio Frequency control (LLRF) system measures the RF signals from the accelerator tube, compares it with the phase reference received from the phase reference distribution system (PRDS）, and provides the drive signal to the high power RF system to provide synchronized RF voltage to the electron beam. Usually, the LLRF system can achieve a ~50 fs RMS phase jitter which is limited by the RF devices and electronic noise. The phase noise arise from the high voltage variation of the high power system will significantly increase phase noise from low level RF signal to high power RF. A high voltage feedforward subsystem(HVFF) is proposed to deal with the phase noise caused by the high voltage jitter of the modulator. The demo system is deployed in Thomson scattering X-ray source (TTX), and the primary experiment result analyses is discussed.

INTRODUCTION

Low Level RF systems (LLRF) close a feedback loop around the high-power RF system and the cavity, stabilizing the accelerating field observed by the beam. The pulse-to-pulse feedback control mode is a common way to be chosen for LLRF system where the amplitude and phase information of the previous pulse signal are used to feed back the next pulse signal [1-3]. In the deployment at TTX, a majority percent of jitter comes from the noise of high-voltage modulator, which needs to be upgraded later for the system better performance [4].

During the process of RF signal amplification through the klystron, the phase difference between the input and output signals of the klystron is mainly affected by the high-voltage signal applied to the klystron tube. The flatness of the high voltage signal within a single pulse or pulse to pulse affects the flatness of the amplitude and phase of the output RF signal. The jitter of the high voltage signal between the pulse will directly result in the phase jitter. This kind of phase jitter is a random short-term jitter and is the main source of fast noise in the entire RF system. In order to provide a feed forward mechanism, the high voltage signal of the modulator needs to be measured before each pulse signal as a standard for the calculation of the feedforward amount.

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THE HIGH VOLTAGE FEEDFORWORD SUBSYSTEM (HVFF) OF THE LLRF SYSTEM

The high voltage feedforward subsystem is an insertion part of the LLRF system in hardware, as shown in Fig. 1. The HVFF measures the voltage from the modulator, and transforms the variation of the voltage to the phase variation. Such phase noise caused by the modulator can be removed in the algorithm in the LLRF46 board.

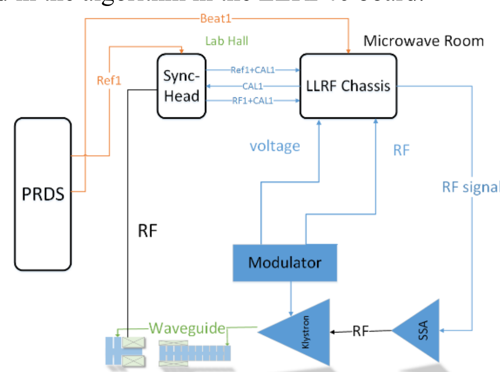

Figure 1: The scheme of HVFF in LLRF system.

The Configuration of Voltage Acquisition Module

The HVFF subsystem aims to deal with the phase noise caused by the modulator voltage variation, as showed in Fig.1. The modulator high-voltage amplitude jitter is about 0.01%, so at least a 14 bits ADC device is needed.

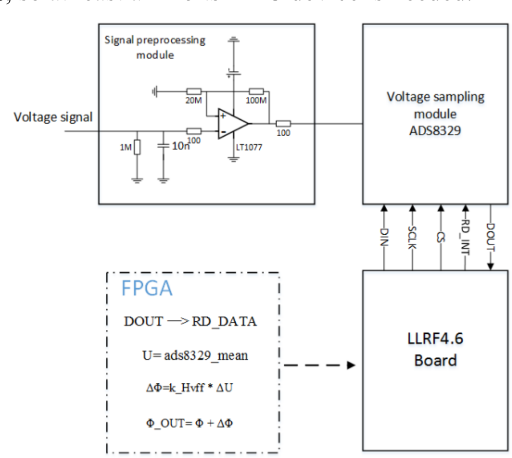

Figure 2: The configuration of the voltage acquisition module with ADS8329 device.

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As shown in Fig.2, the lower power, 16 bit, unipolar input ADS8329 is chosen for the voltage acquisition module, the sampling rate is 1MHz, using Serial Peripheral Interface (SPI) protocol to communicate with LLRF46 board. The voltage acquisition module includes signal preprocessing module for signal filter and amplification and voltage sample jitter of the voltage the sampling module is 2~3lsb, hence the effective bit is about 15bit RMS.

The Proportional Coefficient Between the Voltage Variation and RF Phase Noise Variation

In order to provide a feed forward mechanism, the high voltage signal of the modulator needs to be measured before each pulse signal as a standard for the calculation of the feedforward amount. Showing in Fig.3, The relationship between the phase noise arise from the high voltage variation of the high power system and the phase noise from low level RF signal to high power RF is: $\Delta\Phi = k\_HVFF * \Delta U$. The proportional coefficient k need to be measure in experiment.

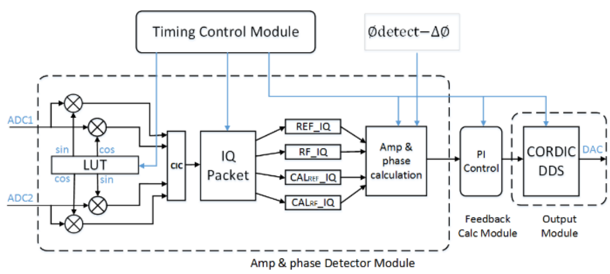

Figure 3: The digital signal processing of HVFF.

Adjust the high voltage of the modulator under the low-level system phase open loop mode, the interval time is 10s. Record the RF phase in the electron gun and the voltage of the modulator for several times. The k is about 9.6°/kV, as shown in Fig.4.

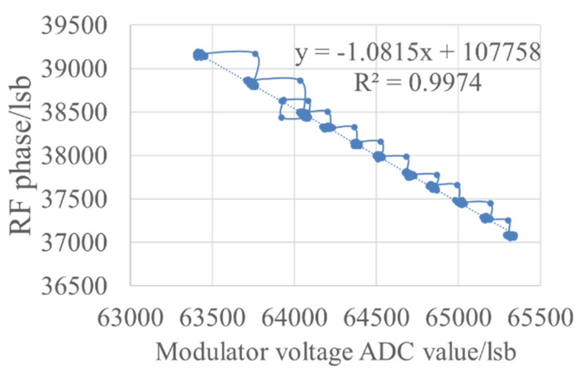

Figure 4: The proportional coefficient k.

THE PERFORMANCE OF THE HVFF SYSTEM IN TTX

The Test Result of On the Old Modulator

It is seen from Fig. 5 that the modulator voltage has a period of fluctuations about 20 seconds, the wave amplitude is about 20lsb.

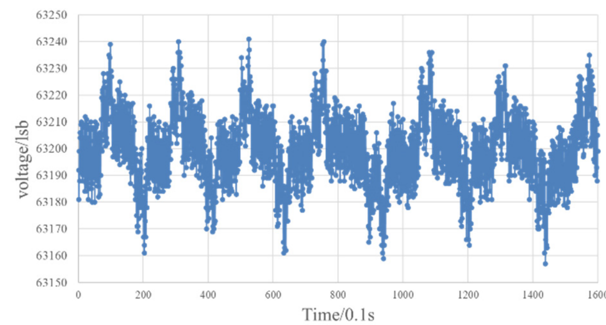

Figure 5: The voltage variation of the modulator detected by the voltage acquisition module.

According to Fig.6, the experimental result on the old modulator shows that the phase noise of high frequency signals is significantly suppressed after the HVFF subsystem is turned on.

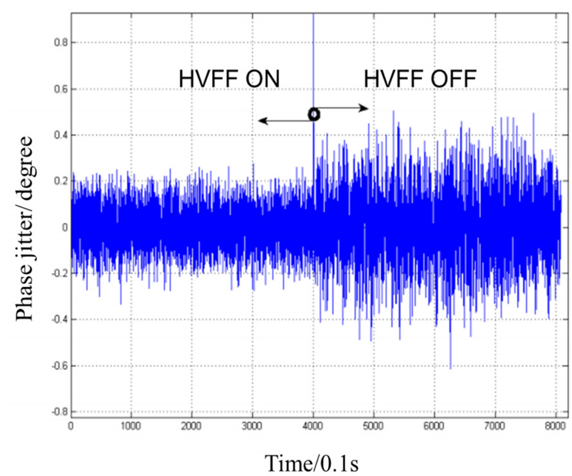

Figure 6: The test result of the RF phase jitter before and after the HVFF off.

According to the obtained voltage-phase relationship, the HVFF subsystem calculates the phase compensation value of RF phase and adds it in the drive RF phase, correcting the phase of the signal when it is out, and eventually achieving the purpose of feedforward. When the HVFF system is off, the RMS jitter is approximately 148fs RMS, and the phase RMS jitter is suppressed to 91fs RMS after it turns on.

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The Optimal RF Control Accuracy Analysis

The theoretical control accuracy depends on the measurement accuracy of the modulator voltage sampling accuracy:

(93-1.76)/6.02=15.2bit (under 16.7kHz)

and the actual measurement is about 15bit. Therefore, for this high-voltage feedforward system, the correction accuracy is approximately:

(3/2sqrt2 * 1.1)/2^16/2856*10^9 = 6.29 fs RMS

Actually, the RF phase is affected by several effects like the circuit noise, the cooling water and the power supply noise and so on. After the optimization of the whole LLRF system and the RF system, the phase noise in the electron gun is about 70 fs RMS in Tsinghua accelerator lab.

CONCLUSION

A high voltage feedforward subsystem of low level RF system is proposed to deal with the phase noise arising from the high voltage variation of the modulator. This kind of phase jitter is a random jitter leading to the main source of the LLRF system fast jitter. The demo system is built in Tsinghua accelerator lab. The test result shows the HVFF system can effectively reduce the noise caused by the modulator voltage variation, which may be applied in old modulator maintenance and updating.

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