MODIFIED TRIGGER MODE OF STREAK CAMERA TO MEASURE BUNCH LONGITUDINAL DISTRIBUTION IN HLS II*

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Abstract

In Hefei Light Source, the streak camera was used to measure the bunch length and longitudinal distribution using synchronous light. As the RF frequency of HLS II was 204 MHz, the streak camera worked at the frequency of 102 MHz (half of 204 MHz). Because of the bunch lengthening, the streak camera faced the problem, the streak image on the phosphor screen will overlap when the bunch length was above 200.5 ps@5% linear error and 10% overlap. In order to solve this problem, an effective solution was to change the working frequency of the streak camera to 136 MHz (two thirds of 204 MHz), and then the streak image on the phosphor screen will overlap when the bunch length was above 285.6 ps@5% linear error and 10% overlap. So a front-end electronic was needed before the synchronizing signals feed into the streak camera. The front-end electronic was designed to convert the 204 MHz synchronizing signal to 136 MHz.

INTRODUCTION

Hefei Light Source is an electron storage ring with 800 MeV energy, and its RF frequency is 204 MHz. When it is working under single-bunch patterns, the bunch space is 220 ns and the natural bunch length is 110 ps [1]. Besides when it is working under multi-bunch patterns, the bunch length is about 240~305 ps while the beam current is from 100 to 200 mA [2]. Because of the bunch lengthening, the bunch length is increasing rapidly along with the increase of the beam current [3]. The streak camera used to work at a frequency of 102 MHz, but the measurement got error when the bunch length was above 200.5 ps @5% linear error and 10% overlap. It has been confirmed that the streak camera could avoid the error if changing its working frequency to 136 MHz when the bunch length is under 285.6 ps in theory, so we designed and made a front-end electronic to realize the frequency conversion from 204 MHz to 136 MHz. In this paper we will introduce operating principles of the streak camera, synchronous sweep under different trigger modes and the front-end electronic.

INTRODUCTION TO STREAK CAMERA

A streak camera developed at Optronis Company in Germany was adopted in HLS II. Streak camera is an instrument to measure ultra-high-fast optical phenomenon and it can provide intensity, time and location information of the light.

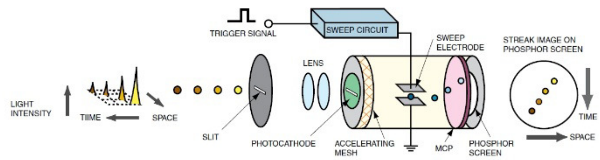

Figure 1: Operating principle of the streak camera.

Figure 1 shows operating principles of the streak camera. The light being measured first passes a slit, and is formed into a slit image on the photocathode of streak tube by an optics system. There, four optics pulses which have slightly difference in space and time and different intensities reach the photocathode through the slit. The light reaching the photocathode is converted into series of electrons proportional to the light intensity. Then, these electrons pass a pair of accelerating electrodes where they are accelerated and struck against the phosphor screen. When electrons generated by four optics pluses pass a pair of sweep electrodes, the relationship between the incident light and the high voltage applied to the sweep electrode is shown in Fig. 2.

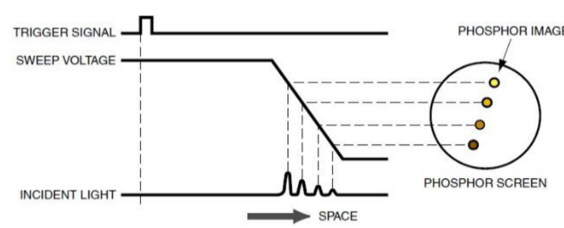

Figure 2: Operating timing (at time of sweep).

During the high-speed sweep, the electrons having a slight time lag will have a different angle deflection in vertical direction and then enter the MCP. When passing the MCP, the electrons are amplified thousands of times, and then strike against the phosphor screen converting into light again. On the phosphor screen, the phosphor image on the uppermost position corresponds to the earliest optics pulse and other images are in order from the top to the bottom. Meanwhile, the brightness of the phosphor images is in direct proportion to the intensity of incident optics pulses [4].

In this way, we can obtain the incident optics intensity from the brightness of the phosphor image, and the time and position from the location of the phosphor image [4].

The streak camera measurement system in HLS II is composed of trigger unit, synchrotron light extracting unit, OPTOSCOPE streak camera, readout unit, frame-grabber board and computer. The system configuration is shown in Fig. 3 [5].

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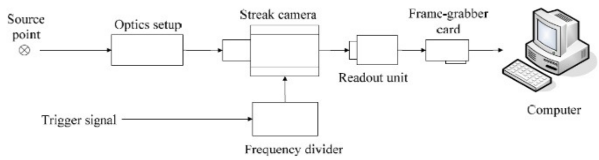

Figure 3: The system configuration of streak camera.

SYNCHRONOUS SWEEP

The streak camera used to work at a frequency of 102 MHz in HLS II, the scan speed of FSSU1-ST is 100 ps/mm, the time range is 1950 ps. Under these conditions, the unit time sequence of synchronous sweep is shown in Fig. 4. Because the harmonic number is 45, when the trigger signal triggers at zero point of the sweep signal, the bunch will appear on the mid of phosphor screen (see mid of Fig. 4) and format a streak image. In this case, the head and tail of the image will get overlapped. Therefore, we cannot observe the tilt of longitudinal distribution caused by potential well effect. By delaying the trigger signal, the trigger signal triggers at an appropriate position of sweep signal, then two streak images of bunch in positive and negative half cycle are shown on the phosphor screen (see bottom of Fig .4). At this time, the tilt of longitudinal distribution caused by potential well effect can be observed. However, if the bunch length is larger than 227 ps@10% overlap or longitudinal vibration amplitude is out of range, the overlap is still existed. If the linear error is less than 5%, the bunch length should be less than 200.5 ps. So, in order to avoid overlap and to reduce linear error, the bunch length should be less than 200.5 ps. That cannot meet the requirement to measure the bunch length and longitudinal distribution in HLS II. So we have to make improvement to the trigger mode of the streak camera.

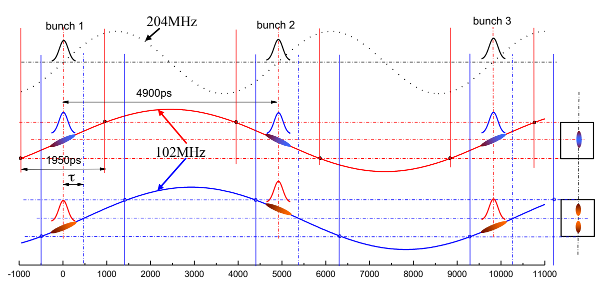

Figure 4: The unit time sequence of synchronous sweep under half RF frequency.

An improvement is to make the streak camera working under two third of RF frequency. In this case, the unit time sequence of synchronous sweep at this time is shown in Fig. 5. Due to two thirds of RF frequency which is 136 MHz, only one bunch within every three bunch can be triggered at zero point of the sweep signal, so only one streak image is formatted on the phosphor screen. The overlap is certainly existed when the bunch length is larger than 285.6 ps@10% overlap or longitudinal vibration amplitude is out of range. If the linear error is less than 5%, the bunch length should be less than 300.7 ps. So, in order to avoid overlap and to reduce linear error, the bunch length should be less than 285.6 ps. Therefore, the bunch length measurement range of streak camera is increased using two thirds of RF frequency in HLS II.

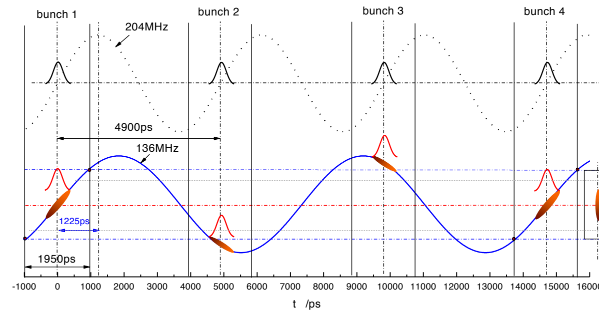

Figure 5: The unit time sequence of synchronous sweep under two thirds RF frequency.

FRONT-END ELECTRONIC

As the RF frequency of HLS II was 204 MHz and the working frequency of the streak camera should be 136 MHz, we designed a front-end electronic. ADF4360-8 chip of Analog Devices was selected. The ADF4360-8 chip is an integrated integer-N synthesizer and voltage-controlled oscillator (VCO). The input frequency of the chip is between 10 MHz and 250 MHz, and the chip allows an output frequency range from 65 MHz to 400 MHz [6]. What's more, the ADF4360-8 chip has a structure of phase-locked loop (PLL). A PLL is a circuit synchronizing an output signal with an input signal in frequency as well as in phase. In our front-end electronic, the frequency of input signal is 204 MHz, and the frequency of output signal is 136 MHz. Meanwhile, under synchronous sweep, the trigger signal and the sweep signal need to be synchronous in phase, so the ADF4360-8 chip is suitable. The chip's function block diagram is shown in Fig. 6.

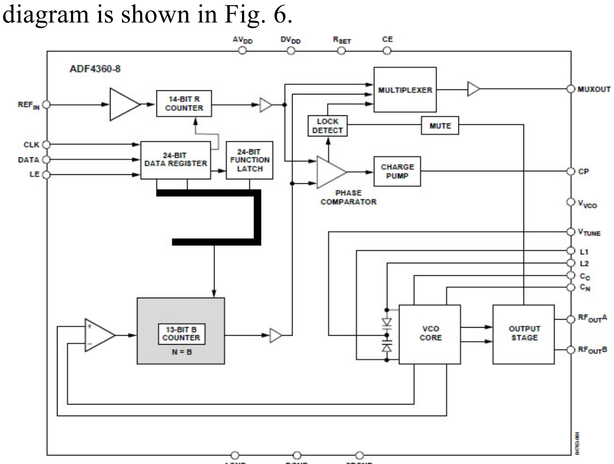

Figure 6: Function block diagram of ADF4360-8.

The ADF4360-8 chip includes a 14-bit R counter, a 13-bit B counter, a 24-bit data register, a 24-bit function latch, phase comparator, multiplexer and VCO. The VCO frequency follows the equation [6]

$$f_{VCO} = B \times f_{REFIN} / R \qquad (1)$$

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where: f_{VCO} is the output of VCO, B is the present divide ratio of the binary 13-bit B counter, f_{REFIN} is the input external reference frequency, R is the present divide ratio of the binary 14-bit R counter.

In our front-end electronic, f_{REFIN} was the RF frequency (204 MHz), the output frequency was equal to the VCO frequency, so we could determine the value for each counter: B=136 and R=204. Therefore, we could get the frequency of output signal,

$$f_{out} = f_{VCO} = 136 \times 204MHz / 204 = 136MHz \qquad (2)$$

On account of PLL of the chip, the output signal would be synchronous with the RF signal in phase.

There were three on-chip latches in the ADF4360-8. The three latches determined how the chip works. According to the manual for ADF4360-8 [6], a particular value was set for each latch: R counter latch is 0x300331, N counter latch is 0x008802, Control latch is 0x0FF1C0.

Since the ADF4360-8 chip had integrated with most of the components of the circuit, we need to design the loop filter which completing the whole phase-locked loop circuit and the control modules which driving the circuit. We used the software "ADIsimPLL" supplied by Analog Devices to design the loop filter, shown in Fig. 7.

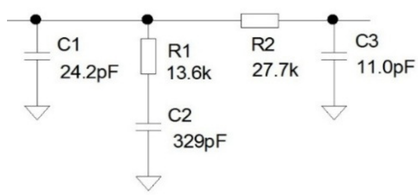

Figure 7: The loop filter.

As for the control modules, we needed a MCU. We chose the STC12LE4052AD chip of STC Inc. to drive the circuit. The STC12LE4052AD is a low-voltage, high-performance CMOS 8-bit microcomputer with 4K bytes of Flash programmable and erasable read-only memory. The port: CLK, LE, DATA of ADF4360-8 should be connected to STC12LE4052AD [7], and then a program was written to drive the MCU to change the ADF4360-8 chip's register values to make the circuit properly functioning and exporting the suitable signals. We wrote a program to generate the hex file which is written into the STC12LE4052AD chip. Then the MCU chip would drive the ADF4360-8 chip to realize the frequency conversion. The full hardware circuit is shown in Fig. 8.

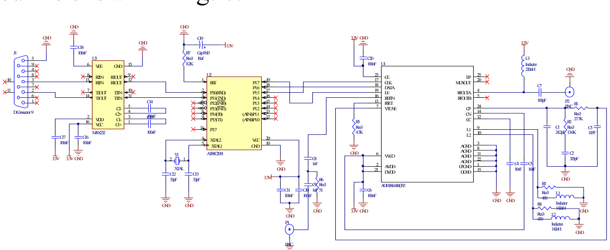

Figure 8: The full hardware circuit.

Then we designed and made the PCB board, welded electronic chips and components and eventually made the actual circuit board, shown in Fig. 9.

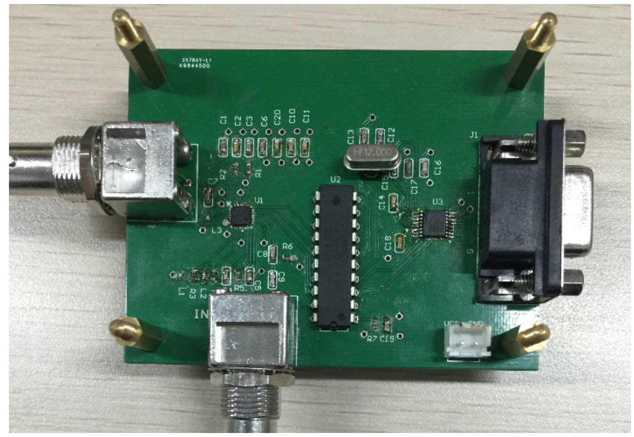

Figure 9: The actual circuit board.

In the offline test, we have tested the series port communication between the circuit and computer, so the program could be downloaded to the MCU successfully. In the next, we will do further test on the output signal.

CONCLUSION

In this paper, we introduced the principles of the streak camera and its system configuration in HLS II. We also introduced the modified trigger mode of the streak camera under synchronous sweep. Besides, we designed and made a front-end electronic for the streak camera. We used an integer-N synthesizer ADF4360-8 chip to realize the frequency conversion. The further work is to test the circuit and to use the front-end electronic into the streak camera system in HLS II.

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