A new design of seed source used in optical streak camera

Wang Qiaoli[1,2], Bai Yonglin[1], Zhu Bingli[1], Wang Bo[1], Gou Yongsheng[1], Jin Jing[1,2]

(1. State Key Laboratory of Transient Optics and Photonics, Xi′an Institute of Optics and Precision Mechanics, Chinese Academy of Sciences, Xi′an 710119, China; 2. University of Chinese Academy of Sciences, Beijing 100049, China)

Abstract: A new technique to generate high frequency repeated sine synchronous scan seed source was introduced, based on the method of phase locked loop and direct digital synthesize technique. Phase locked loop was used to realize synchronous track of sine scan signal and trigger light impulse. Modulation of frequency, phase, and amplitude was achieved by direct digital synthesize technique. Delay of scan time was achieved by phase modulation, while different scanning rate was achieved by amplification modulation. The circuit system can obtain stable sine synchronous scan seed signal with frequency as high as 250 MHz, and jitter lower than 10 ps. The design is confirmed to meet the expectation, and fulfill the high precision requirements of streak camera on seed source for frequency, amplitude and time jitter.

Key words: synchronous scan; optical streak camera; phase locked loop; direct digital synthesize; time jitter

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一种用于光学条纹相机的种子源设计

王桥莉[1,2],白永林[1],朱炳利[1],王 博[1],缑永胜[1],靳 晶[1,2]

(1. 中国科学院西安光学精密机械研究所,瞬态光学与光子技术国家重点实验室,陕西 西安 710119;
2. 中国科学院大学,北京 100049)

摘 要:介绍了一种基于锁相环及频率合成方法产生高重复频率正弦同步扫描种子源产生技术。利用锁相环实现了正弦信号与触发光脉冲的同步跟踪,并通过频率合成实现对正弦小信号的频率、相位、幅度的调制。调制相位可实现扫描时间的延迟,调节振幅可实现不同扫描速度。电路系统进行了实验测试,获得频率可达 250 MHz、时间抖动小于 10 ps 的稳定正弦同步扫描种子源,证明设计达到了预期目标,满足光学条纹相机对种子源频率、幅度、抖动的高精度需求。

关键词:同步扫描; 光学条纹相机; 锁相环; 频率合成; 时间抖动

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作者简介:王桥莉(1986-),女,硕士生,主要从事超快诊断技术方面的研究。Email:wqiao3611@163.com

导师简介:白永林(1972-),男,研究员,博士,主要从事超快诊断技术方面的研究。Email:baiyonglin@opt.ac.cn

0 Introduction

Optical image tube streak camera especially synchronous streak camera is a very important diagnosis tool of sub picosecond time resolution, and plays an important role in the diagnosis of ultrafast phenomena such as ultrafast fluorescence spectrum imaging and femtosecond time detection. The deflection plate in the image tube needs to scan the synchronous scan circuit to get scan signal. Jitter and frequency of the picosecond synchronous scan circuit determine some key parameters of the synchronous streak camera such as time resolution and spatial resolution. Traditionally, synchronous scan circuit is achieved by the combination of a stable circuit and a filter circuit[1,2], which is structured by tunnel diode. Signal amplitude and phase generated by this method are fixed, and the output amplitude is too small to fulfill the sensitivity requirements of the image converter tube. To modulate the amplitude or phase in the circuit, device parameter of the circuit should be changed, which is a very complicated process. Also, time shift of tunnel diode can be easily changed by circumstance, which influences time resolution of the synchronous streak camera terribly[3].

We attempt to use phase locked loop (PLL) and direct digit synthesis(DDS) technique to generate seed source in the synchronous scan circuit. The seed source can load over the deflection plate of the image converter tube directly after zoom matching. The circuit also has advantages over tunability of amplitude and that of frequency and time jitter. The whole system integrates micro-processor to achieve automation of frequency detection and phase lock. The method is meaningful to the realization of synchronous scan streak camera and precision diagnosis.

1 Principle of synchronous scan

The working principle of the synchronous scan camera is shown in Fig.1. High frequency laser impulse splits into two beams by the optic system. One of the two beams is led to the photocathode, generates an electron beam, which is led to deflection plate finally. The other beam generates slight electric signal by a photodiode, which is then used as the source input of the synchronous scan circuit. A sine signal of the same frequency with the input electric signal can be generated by the scan circuit. Then, the sine signal is amplified and resistance matched, and eventually led to the deflection plate. The quasi linear area of the sine signal can scan electrons going through the deflection plate, and make the electrons shift certain distance both horizontally and vertically. Then the shifted electrons are amplified and imaged on Charge Coupled Device (CCD).

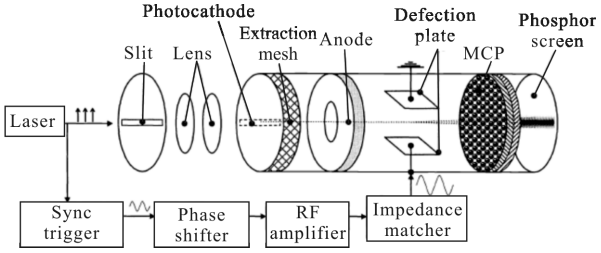

Fig.1 Principle of synchronous scan camera

Figure 2 shows the principle of synchronous scan using quasi linear part of sine signal to scan the input photoelectrons repeatedly, and the weak signal is accumulated to be strong enough to be detected [4]. The quasi linear part of the sine signal should be strictly synchronous to the input light impulse in the whole process, which makes the system very sensitive to the phase jitter of seed source[5]. If time jitter of the sine scan signal applied on deflection plate is large enough, displacement of the scanned signal will be deviated from initial place in both directions, which will affect time and spatial resolution of streak camera greatly.

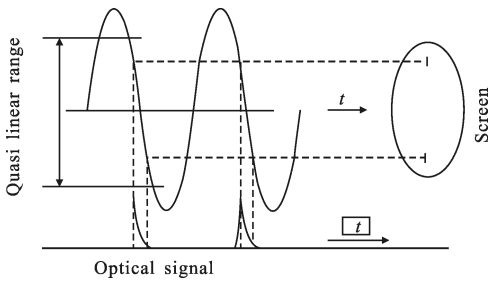

Fig.2 Synchronous principle of sine scan signal

2 Synchronous sine scan seed source signal generator

Synchronous sine signal was generated by PLL and DDS. The input light impulse generates electric sine signal after going through a high speed PIN and pretreatment. Then, the electric signal splits into two arms. One of them went through a frequency detection circuit to estimate the frequency to provide correlated circuit modulation parameter for the control system. The other one was led to PLL, of which the frequency track function can be used to track and lock the frequency of trigger impulse[6]. Direct digit synthesizer can be used to generate sine scan signal[7]. Also, the synthesizer can modulate phase and amplitude of the seed source. Delay of scan time can be achieved by phase modulation, and different scan rate can be achieved by tuning of amplitude.

Schematic of the system is shown as Fig.3. The output electric impulse of photodiode and output of voltage control oscillator (VCO) are used as the input of the phase detector, and phase difference of the two signals ranges from 0 to 360 degree[8]. The phase detector can output voltage deviation signal according to the phase difference of the two signals. Deviation signal was then led to a loop filter to remove the high frequency part and noise. The filtered low frequency voltage signal was used as the control signal of VCO. By operating of the control signal, frequency of the VCO output signal was divided and fed back to the phase detector, which forms a phase lock loop. The phase lock loop made the output clock signal of VCO synchronous to the trigger light impulse. The output signal of VCO was used as the input clock of DDS. Frequency of the signal can be divided by DDS to obtain sine signal of required frequency. Amplitude or phase modulation could be achieved by writing tuning word to the correlated register of DDS[9]. This process is much simpler than that of the traditional mono-stable circuit.

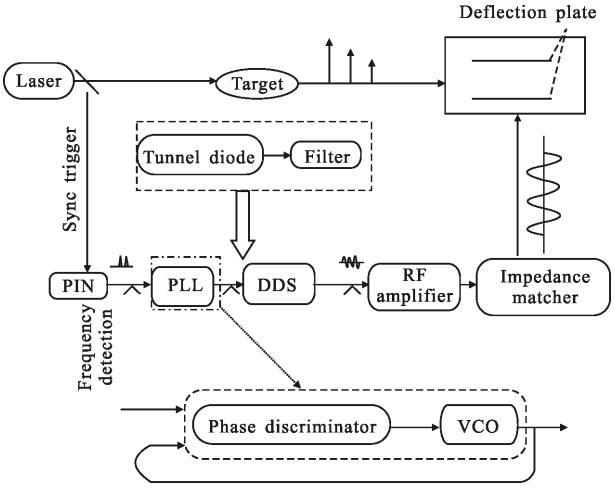

Fig.3 Schematics of synchronous scan circuit

A special frequency detection chip is used in the system to acquire frequency information in different accessions. The information is uploaded to a Main Control Unit (MCU). MCU corresponds with main control module according to host computer or control box, to achieve information acquirement and transformation of signal and instructions, furthermore, to configure parameter of different function modules. Thus, automatic control of synchronous scan circuit module can be achieved[10].

3 Time jitter

After design of system hardware circuit, we measured frequency spectrum and RMS time jitter of the sine scan signal(frequency spectrum was measured by Agilent E4447A spectrum analyzer, and time jitter was measured by 86100c sampling oscilloscope). Figure 4 shows frequency spectrum of scan signal when the input light impulse frequency is 250 MHz. The frequency spectrum has an obvious width seen from the figure. Since frequency spectrum of ideal sine signal should be a single line, the figure indicates that sine signal generated by the synchronous scan circuit has some extent of time jitter. The signal presents to have some harmonic component in the frequency domain and have an expanded frequency spectrum in the frequency domain.

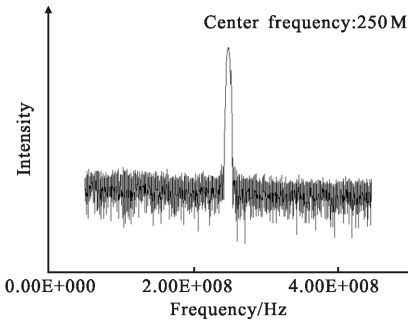

Fig.4 Spectrum of sine scan signal

Degree of signal shaking in the time domain can be evaluated by the RMS value of jitter. If time jitter (RMS) of sine signal is large enough, it will be worse after radio frequency amplification. This will affect time and spatial resolution greatly. So, time jitter of sine signal should be as low as possible. In the measurement of time jitter, light impulse was applied to a high speed PIN diode to convert the light impulse to synchronous electric impulse, which was used as the external trigger signal of sampling oscillator. Figure 5 is the waveform of the scan signal when frequency of the input light impulse is 250 MHz. The figure shows that the sine signal generated by the synchronous scan circuit is of the same frequency as the input light impulse(250 MHz). RMS value of time jitter of the scan signal measured by the sampling oscilloscope is about 9.5 ps, which is very close to the highest level of time jitter in the world, and fulfills the requirements of synchronous streak camera internal.

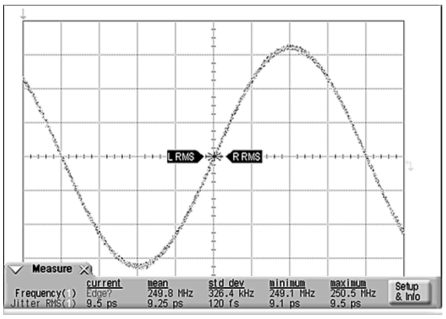

Fig.5 Waveforms of sine scan signal

Time jitter of synchronous scan seed source is mainly caused by light impulse, high speed PIN and synchronous scan circuit. Among the three factors, jitter caused by input light impulse is lower than 30 fs, and is about 1.3 ps contributed by high speed PIN. Therefore, time jitter of synchronous scan source is mainly contributed by the scanning circuit. To achieve better synchronous to the trigger light impulse, time jitter of the scanning circuit should be as low as possible.

In the entire circuit design, time jitter may be influenced by the instability of the trigger light impulse and bandwidths of the filter circuit. So, to reduce time jitter further, devices of high stability should be used and some optimization to the circuit should be performed.

4 Conclusion

We designed a synchronous scan seed source signal generator used in the optical image tube scan camera, based on the modern clock generation and frequency synthesized digit circuit. The generator has the function of phase and amplitude modulation. Highest repeated frequency of the generated signal can be 250 MHz. Time jitter of the generated signal can be less than 10 ps. The whole circuit is highly integrated and is simple to realize. By optimizing the filter circuit further, an even lower time jitter can be expected, and the spatial and time resolution of the streak camera will be much more improved.

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