An Energy Measurement Method of High-frequency Narrow Laser Pulse based on FPGA

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***Abstract*–An energy measurement method used for high-frequency narrow laser pulses based on a high performance field-programmable gate array (FPGA) chip is introduced in this paper. There are two parts contained in this method: signal conditioning and data processing. The signal conditioning part will transform the incident narrow laser pulse to electrical signal which has an appropriate width and the amplitude is linear to the energy of the laser pulse. The electrical signal will be digitalized by a high speed ADC and input to the FPGA chip in the data processing part. The amplitude of the electrical signal will be obtained by real-time calculations in the FPGA. The test result shows that the method is suitable for the laser pulse with FWHW low level with 200ps and frequency up to 20MHz.**

I. INTRODUCTION

WITH the development of laser technology and high-power lasers, the width of laser pulse is becoming narrower, while the peak power is growing, so that the range of narrow laser application is becoming larger, and now the laser with the pulse width in picosecond level have been applied to the physics, chemistry, biology, quantum communication and other fields for a long time, and playing an increasingly important role. Especially, in the Quantum Key Distribution (QKD) experiment, the pulse width of the laser in transmitter is less than 1ns.

In the QKD system based on the decoy-state-BB84 protocol [1][2], a series of laser pulses with random polarization states and intensities are transmitted by the transmitter. There are four polarizations: H, V, P, N and the signal state pulse has an intensity three times of the decoy state pulse while the vacuum state pulse doesn't emit photons [3]. The transmitter also transmits sync-light pulses which have much higher intensities to make sure the information synchronization between the transmitter and the receiver. The sync-light and signal light are coupled into one optical fiber by the WDM technology. In order to debug the system and test the stability of the lasers, the signal light is divided into two paths before coupling and one of the two is connected to the test port of the transmitter as shown in Fig.1. The stability of the lasers and whether the system is working properly can be known by measuring the energy of laser pulses from the test port.

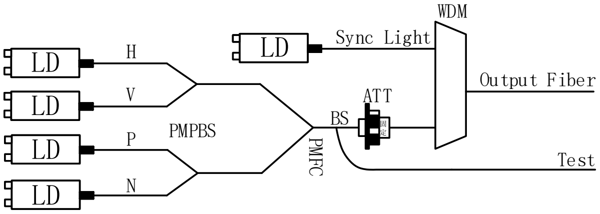

Fig.1 Optics structure of the transmitter

The method of FPGA-based energy measurement of high-frequency narrow laser pulse described in this paper abandons slow peak-value-hold circuit[4][6], only implements signal amplifying and broadening with high speed operational amplifiers, then a high speed pipeline ADC will be used to transform the analog signal to digital data. These data will be appropriately processed real-time inside a high performance FPGA to obtain the amplitude of the electrical signal thus the optical pulse's energy will be known according to the linear relationship between optical pulse's energy and electrical signal's amplitude.

II. SYSTEM DESIGN

The designed system consists of two parts: signal conditioning board and a main processing board with a high speed pipeline ADC.

An optical pulse with an about 200ps FWHW from the test port can be converted to an electrical signal with an about 1ns rising edge and 2ns falling edge by a photon diode. The electrical signal is too narrow to be sampled directly so a signal conditioning circuit is developed to amplify and broaden the electrical signal.

The circuit is mainly made of three parts besides a high speed photon diode (PIN), including a non-inverting amplification part, an active filter broadening part and an inverting amplification part as shown in Fig.2.

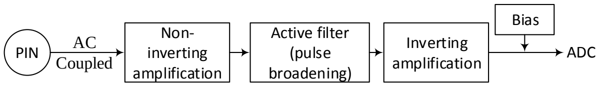

Fig.2 Signal conditioning circuit

The structure of the data processing board including the ADC is shown in Fig.3. The FPGA configures the clock

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generator via a SPI interface to generate a 200MHz LVDS clock to the ADC. As the outputs of the ADC are high speed differential signals, those signal traces should keep the same long length. The length of the two traces inside one differential signal pair should keep 10mils as a margin of error while 50mils for different pairs. The single-ended Clock trace and data traces of the Gigabit Ethernet Transceiver should be as same long as possible too.

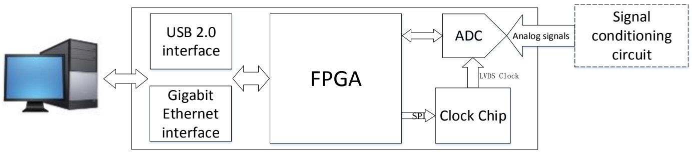

Fig.3 Structure of the data processing

The primary functions of the data processing are signal amplitude acquisition and data transmission. They are all implemented inside the FPGA.

III. TEST RESULT

After multiple simulations and experiments, fig.4 shows the comparison before and after conditioning. The upper waveform in Fig.4 has been broadened while the lower waveform is the original shape stem from the PIN. The signal after conditioning has an about 4ns rising edge and a 15ns falling edge. The summit (part more than 90% of the peak value) is wider than 5ns and quite flat. The signal's amplitude is under 600mV while lasting about 30ns without overlapping.

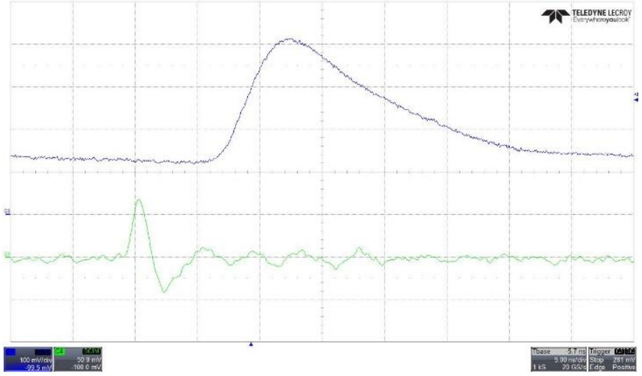

Fig.4 Waveforms before and after conditioning

The stability of the optical pulse's peak power can be known by analyzing the amplitude data uploaded through the Gigabit Ethernet interface. Fig.5 is drawn by 500 continuous points choosing from the uploaded data. The blue polyline is the scatter line of the 500 points and the red straight line is the average value of the 500 points. The average of the 500 points (mean) is 107(has already been rounded to integer), standard deviation is 0.79456 and coefficient of variation (the quotient of standard deviation divided by mean) is 0.74%. Both the standard deviation and the coefficient of variation indicate that the amplitude data have a very low volatility and the functions from the analog-to-digital conversion to the signal amplitude acquisition are highly stable.

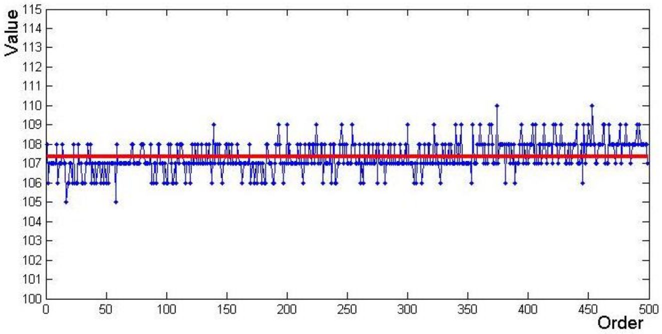

Fig.5 Analysis chart on amplitude data

IV. CONCLUSION

The method described in this paper just uses simple active filter that can reduce obviously the dead time of traditional peak-value-hold circuit and hence can measure the energy of the narrow laser pulse with a frequency up to 20MHz. The signal conditioning circuit can broaden the narrow laser pulse with a FWHW low to 200ps while keeping quite linear and stable. The data processing can obtain the electrical signal's amplitude accurately without any losses. The method can be applied to the fields where energy measurement is needed and is quite suitable for offline analysis of the stability of a laser.

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