NEW DEVELOPMENTS ON SINGLE-SHOT FIBER SCOPE

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Abstract

A Single-Shot Fiber Scope based on optical fiber recirculating loop technology has been developed by YY Labs[1] under support of the US Department of Energy SBIR grant. Beam tests carried out with SLAC beam and with pulse generator were reported in PAC2003[2] and NIM[3]. The device and the method have received US patent in 2004 [4]. Efforts have been made since then to upgrade and improve the instrument. The paper reports the recent developments and the test results, the resolution is better than 5 ps.

INTRODUCTION

The Single-Shot Fiber Scope consists of two separate boxes. One is Transient Signal Capture; the other is Pulse Train Generator. The purpose of the instrument is to capture the single-shot pulse signal, then regenerate them with high fidelity by 1000 or more times, then use a sampling oscilloscope to recover the signal.

Commercially available sampling scope can have 100GHz frequency response, but sampling scope has to work with a repetitive signal. The real time or near real time scope uses interpolation and DSP mathematically to expand the frequency response to 13 or 15 GHz. Since the highest sampling rate is only 40 GS/s, which is 25 ps per sample, for a single-shot signal with 20-ps rise time or FWHM, a different instrument has to be used.

The Single-Shot Fiber Scope utilizes the low-loss, high frequency response of the optical fibers to regenerate the single-shot signal, forming a pulse train for the sampling scope to do the analysis.

With this method, although acquisition rate of the sampling scope is not very high, usually only 200 kHz or even less with commercial available sampling scope, but the equivalent acquisition rate is much higher than the commercially available real time scope. If the signal is displayed in scale of 20ps/div, 512 points per scan, then, the equivalent acquisition rate is: 2560GS/S, 64 times higher than commercially available 40GS/s.

The Single-shot measurements have applications for Accelerator beam instability studies, and also for large power pulsed laser measurement. It may also be used for radar, material science fields.

PRINCIPLES

The instrument measures electrical signals. The electrical single-shot signal is captured and converted into optical signal with the same pulse shape by the Transient Signal Capture box, then delivered to the Pulse Train Generator box with a fiber cable to do the regeneration of the pulses.

The system is shown in Figure 1.

In order to see a bipolar signal, the instrument produces a gating signal. The single-shot signal to be measured will be riding on the top of this gating signal. The gating window is 10 ns wide. As Figure 1 shows, the two original pulse-trains are brought into Channel -1 and Channel -2. A gating signal will capture the particular pulses of interest from Channel -1 and Channel -2. Those two pulses then are riding on the gating signal. The recirculating loop will regenerate them to produce a pulse train, which are separated into two pulse trains to be connected to two channels of the sampling scope.

Each turn is 7.8 µs long. 1000 turns take 7.8 ms.

When the circulation continues, the noise and instability also accumulates and increases. An electronics feedback system has developed to control the loop gain to be unit, and a filtering system has been developed to filter out the noise.

Since every turn a part of the signal will be tapped out, an Erbium-doped fiber amplifier (EDFA) has been used to compensate the energy loss in order to keep the circulation continuing, however, the EDFA is also the source of noise. The amplified spontaneous emission is the main source of the noise in the system. A major effort has been done to develop a low noise EDFA. This has greatly reduced the noise and the instability.

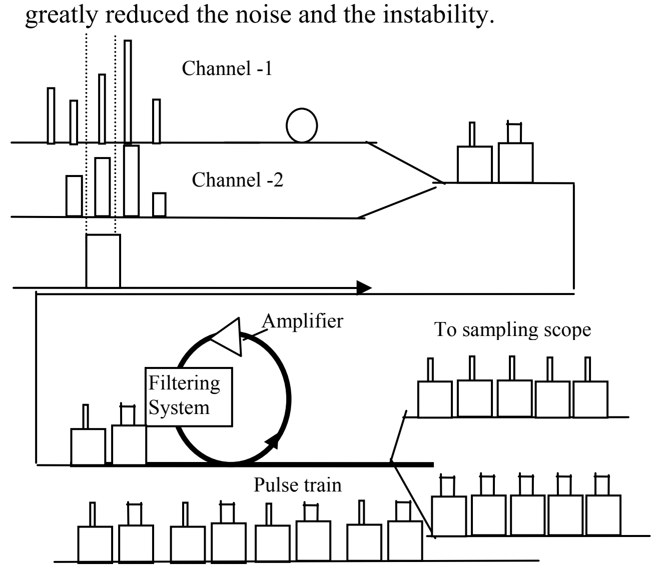

Figure 1: Single-shot fiber scope system

EXPERIMENTAL RESULTS

Figure 2 and Figure 3 show that the circulation of the gating signal, which has reached 1000 and 2000 turns. Figure 4, 5, 6, 7 show that the first, 100th, 400th and the 1001st turn of the gating signal with a captured single-shot signal riding on top of it. They are quite clean without distortion and with good fidelity.

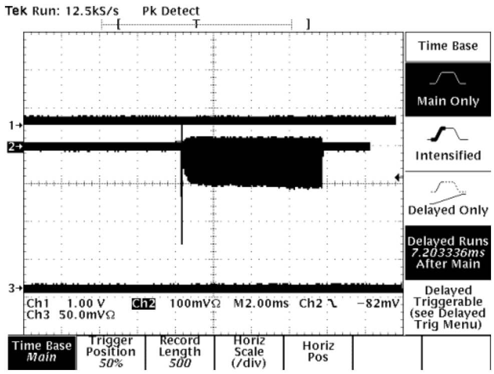

Figure 2: 1000-turn circulations of the gating signal

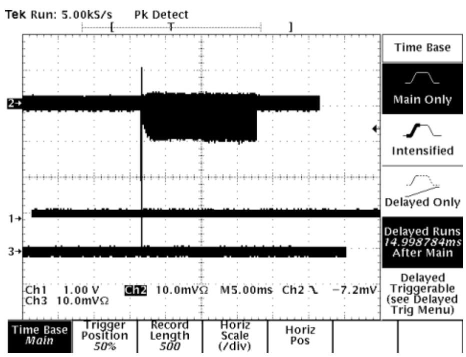

Figure 3: 2000-turn of circulations of the gating signal

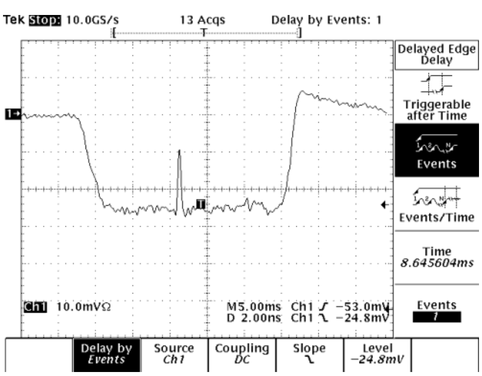

Figure 4: The first turn of the gating signal with a captured single-shot signal

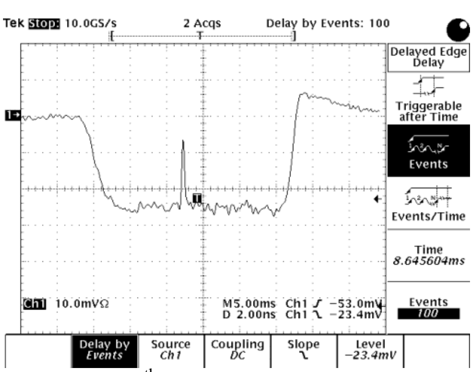

Figure 5: The 100th turn of the gating signal with a captured single-shot signal

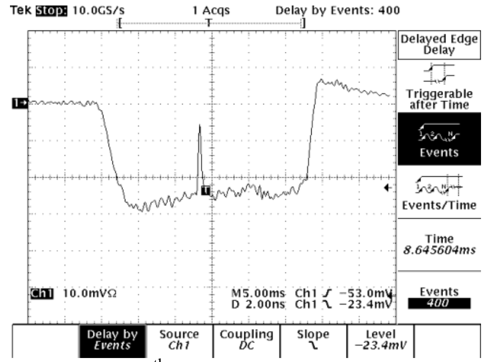

Figure 6: The 400th turn of the gating signal with a captured single-shot signal

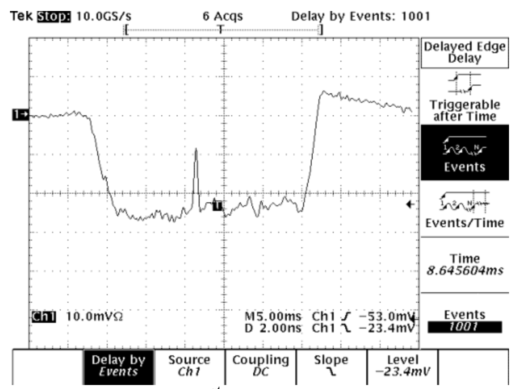

Figure 7: The 1001st turn of the gating signal with a captured single-shot signal.

These signals are then delivered to the sampling oscilloscope to be sampled, and to recover the original signal.

The triggering to the sampling scope is very critical for the whole system. The system uses signal itself as the trigger signal for the sampling scope. The pulse train formed by the recirculating loop is split into two parts, one as the trigger signal; the other one as the signal to be measured is delayed by 140 ns.

A pulse generator from PicoSecond Pulse Lab has been used as single-shot source. A comparison has been made between the original signal and the recovered signal made with the Single-Shot Fiber Scope. Although this has been done previously, but it was done with only 100ps/div, and now we have made it with 50ps/div and 20ps/div. The figures 8-11 show the results of the measurements. A 10GHz photo detector was used to convert the optical pulse train into an electrical pulse train, which then was delivered to the sampling scope. The little bit difference in the rising edge and falling edge in Figure11 are due to the frequency limit of the 10GHz photo detector. Figure 12 shows the set up of the Single-shot measurement system.

The Single-Shot measurements have applications for beam bunch-to-bunch instability studies, and also for high-power pulse laser measurement, for Radar system, and semiconductor material science studies.

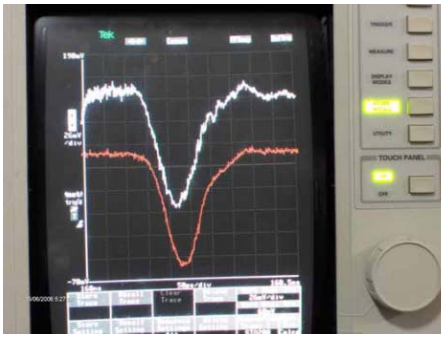

Figure 8: White (top): Recovered signal from the Single-Shot Fiber Scope
Red (bottom): Original signal produced by the Impulse Signal Generator
Time scale: 50ps/div.

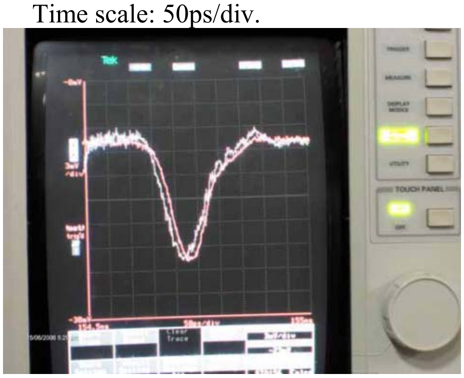

Figure 9: White: Recovered signal
Red: Original signal
Time scale: 50ps/div.

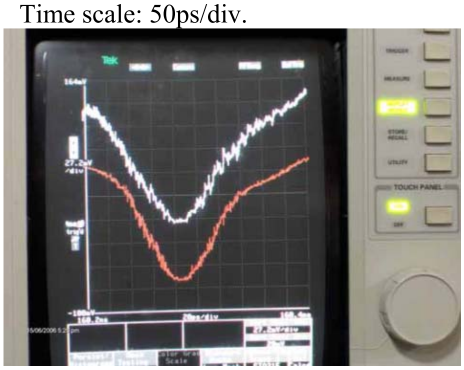

Figure 10: White (top): Recovered Signal
Red (bottom): Original signal
Time scale: 20ps/div

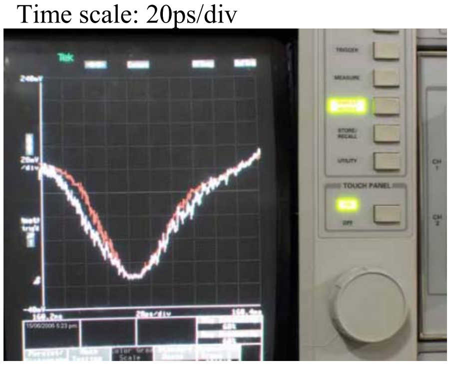

Figure 11: White: Recovered signal
Red: Original signal
Time scale: 20ps/div

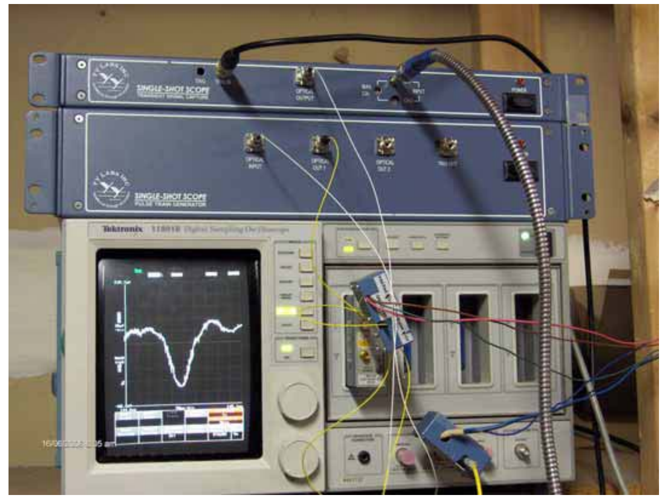

Figure 12: Configuration of the Single-Shot Fiber Scope System

CONCLUSIONS

The work demonstrates a good increase of the frequency response of the single shot scope. Frequency response is above 20 ps. The resolution depends on the sampling scope and the noise of the Single-shot regenerator. While the sampling scope resolution can go down to as low as 1.7 ps due to jittering, the whole system shows at least 5-ps resolution. The use of such an instrument opens new opportunity to the transient signal measurements.

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