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Multichannel single-shot transient signal measurements with a fiber delay line loop ☆

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Abstract

An instrument has been developed to measure single-shot electrical transient signals, in two channels, with frequency responses above 10 GHz (http://www.YYLabs.com). This instrument, which is named Fiber Loop Single-Shot Scope, utilizes an optical fiber recirculating delay line loop to regenerate captured single-shot signals, and then recovers the original single-shot signals with a sampling scope.

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1. Introduction

Commercially available real-time oscilloscopes for the study of beam instability of Linacs or storage rings give frequency responses up to 6 GHz. For frequencies above 6 GHz, the only available instrument is the streak camera, which measures optical signals. Therefore, for the performance of such measurements, electrical signals must be converted to optical signals. The streak camera turns the optical signals into low-energy photoelectrons, and then uses a fast sweeping electrical field to deflect the photoelectrons. The longitudinal intensity distribution of the charged-particle beam is represented as a transverse trace of the photoelectrons displayed by a CCD camera.

YY Labs' Fiber Loop Single-Shot Scope is illustrated in Fig. 1. The principle of this instrument, as shown in Fig. 2, is based on fiber recirculating delay line loop technology, which has been widely used for studying long-haul signal transmission in optical fibers [1]. The Scope captures the single-shot signals in one or two channels, and then regenerates the signals with the aid of a recirculating optical-fiber delay line loop.

The signals recirculate in the loop up to several thousand turns. A small portion of each signal is tapped out at each turn, thus providing copies of the original signal. The energy loss is compensated for with an optical amplifier, and the original amplitudes of the signals are recovered. A sampling scope is utilized to obtain the original signal from the pulse train.

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Fig. 1. YY Labs' Fiber Loop Single-Shot Scope.

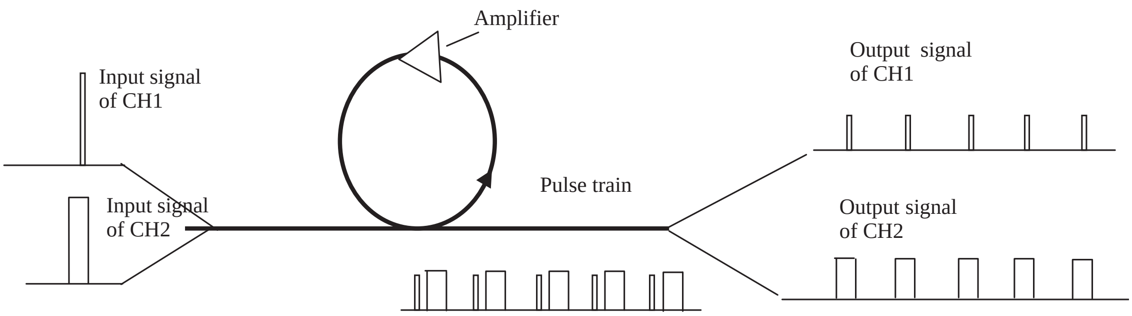

Fig. 2. Principle of the recirculating loop.

The instrument is assembled in two boxes. One box is labeled "Transient Signal Capture," since in it, the single-shot transient signal is acquired. The other box is labeled "Pulse Train Generator," since it regenerates the two-channel single-shot signals, with the formation of two pulse trains. The Transient Signal Capture box is located close to the source of the signal; the Pulse Train Generator box is located in the control room. The linking distance between the two boxes is restricted by the signal transmission limitation of the RS232 cable. The configuration involved is represented in Fig. 3.

The instrument has a gating function, which allows the instrument to select one signal from a series of signals, or gate the single-shot signal for performing measurements. The gate width is adjustable from 5 to 10 ns.

For the purpose of capturing the signal, the instrument has an auto-scan function. If the approximate delay time between the trigger signal and the signal to be measured is known, the delay

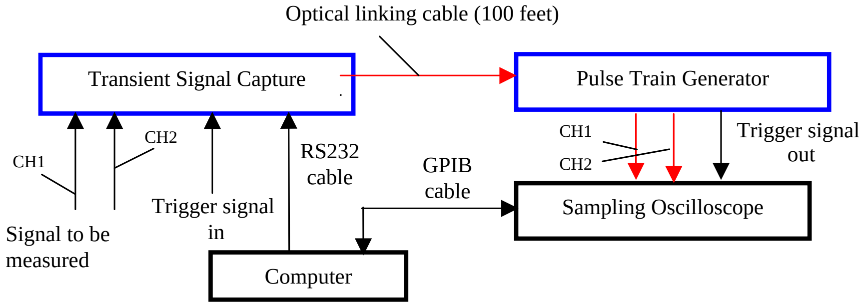

Fig. 3. Fiber Loop Single-Shot Scope configuration. CH, channel.

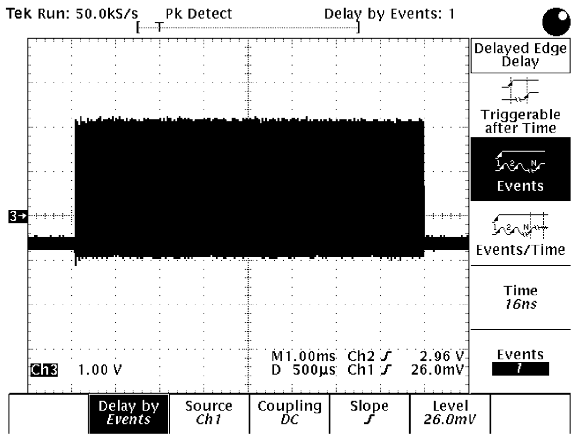

Fig. 4. Circulation of 1000 turns.

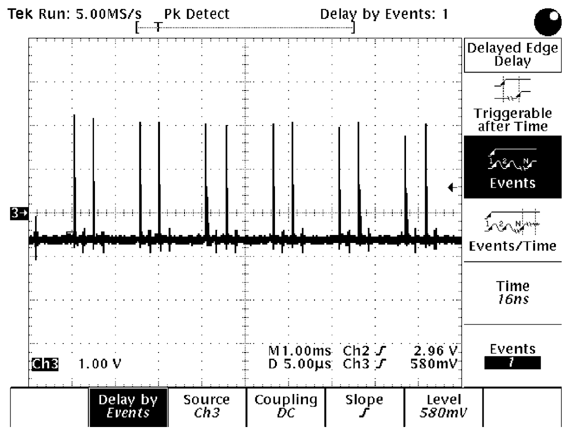

Fig. 5. Circulations of two signals.

time can be set via the computer. If the delay time of the signal is unknown, an approximation should be made, and the auto-scan function will locate and capture the signal. The scan range is 256 ns.

The instrument can measure two single-shot signals simultaneously. The two single-shot signals will be captured and injected into the fiber loop for circulation, and will form two separate pulse trains after they have left the loop, as also represented in Fig. 3.

The number of circulations of the signal in the delay line loop is set at 1000. Each circulation takes 8 μs. Fig. 4 illustrates the signal circulation of 1000 turns, which takes 8 ms.

Fig. 5 shows part of the circulation for a pair of pulses representing two different single-shot signals.

The advantages of using this method reside in the high-frequency response and the low loss of optical fiber, because, in this frequency range employed, the electrical method cannot be used due to problems of loss, dispersion, and reflection. Regarding the optical fiber, with a core diameter of only 9 μm and attenuation of 0.2 dB/km, frequency responses of up to the 20 GHz range can easily be reached.

With the recirculating-loop method, a high-frequency instrument can be constructed with optical-fiber components and relatively low-frequency electronics. Thus, in conjunction with a sampling oscilloscope, a low-cost multichannel, high-frequency single-shot transient signal scope can be built. This PC-based, button-free instrument is user-friendly.

For the tests performed, 10 GHz photodiodes were used, which limited the frequency response to 10 GHz.

Beam tests, as described here, were carried out at Stanford Linear Accelerator Center (SLAC).

2. Beam tests performed at SLAC

The PEP-II is an e^+ e^- collider with asymmetric energies, in the 2200 m tunnel of SLAC [2]. The PEP-II facility consists of two independent storage rings, one on top of the other, in the PEP tunnel. The high-energy ring stores a 9 GeV electron beam, and the low-energy ring stores a 3.1 GeV positron beam.

The signal was taken from a button-type capacitive pick-up of 15 mm diameter, in the straight section of Region 4, 350 m from the interaction point, where the BaBar detector is located. The PEP-II was operated in multibunch mode, with e^+ and e^- circulating in the rings. The rms bunch lengths, σ, of the e^+ and e^- beams are in the range of 11–12 mm, which is equivalent to 40 ps or to a FWHM of 90 ps. Without access to the tunnel, it was not possible to place the signal capture box near the beamline, and the signal, therefore, was brought to the measurement room through an existing 35 m Heliax cable (LDF2-50). Despite the quality of the cable, the high frequencies were somewhat attenuated, and the signal was stretched. For this reason, the pulse length measured was about 174 ps, with a rise time of 164 ps, and fall time of 140 ps (from peak to baseline).

Fig. 6 shows the e^+ beam signal measured by the Fiber Loop Single-Shot Scope. Since the gating signal generator of the instrument has a DC offset, the baseline of the signal is not at 0 V.

The measurement in Fig. 7 was performed directly with the TEK11801 sampling scope and a trigger pulse produced by the RF signal, one pulse for each turn of the beam. Although Figs. 6 and 7 are similar, there is some discrepancy, which is being studied.

Fig. 8 shows six beam bunches, from SLAC PEP II, captured by the instrument. The gate width is 40 ns. The top line of the gating signal represents the baseline of the measured signals.

Fig. 9 is an actual picture, taken at the time of the measurement, obtained by zooming in on one of the bunches in Fig. 8, adjusting the delay time of

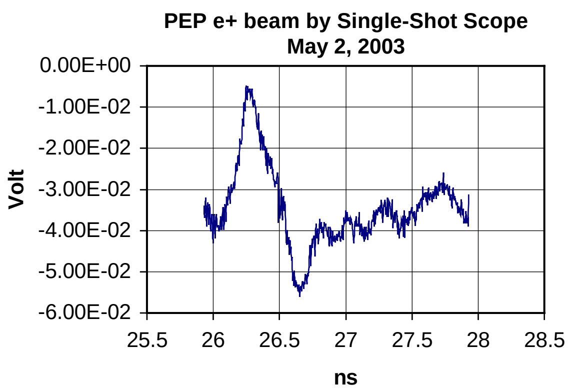

Fig. 6. PEP-II e^+ beam bunch longitudinal distribution measured with the Fiber Loop Single-Shot Scope.

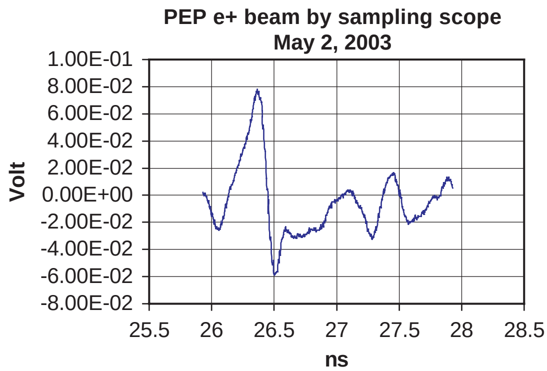

Fig. 7. PEP-II e^+ beam bunch average longitudinal distribution measured directly with the TEK 11801 sampling scope.

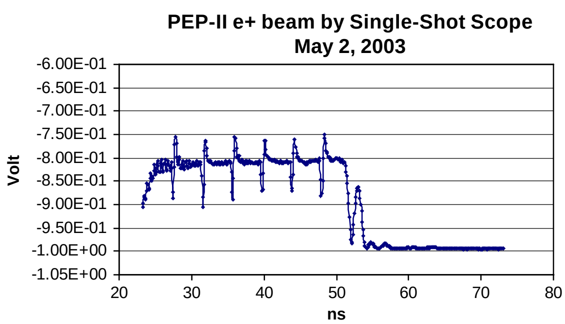

Fig. 8. Measurement of e^+ bunches captured by the Fiber Loop Single-Shot Scope.

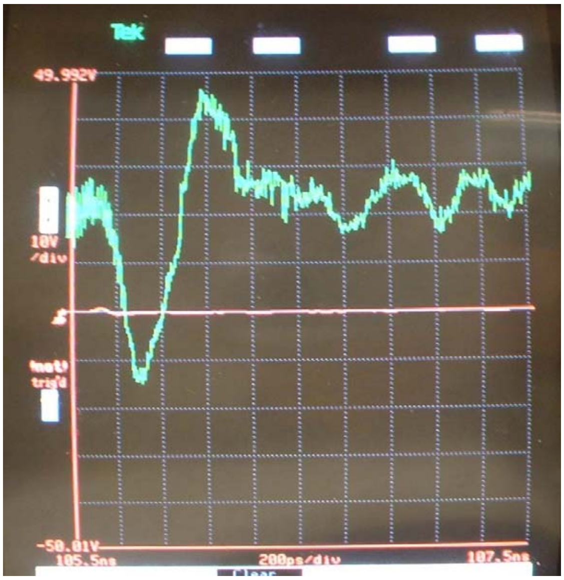

Fig. 9. PEP-II e^+ beam measured by the Fiber Loop Single-Shot Scope.

the sampling scope, and setting the time scale at 200 ps/div. The signal shown is negative, because the slope of the modulator working function, which converts the electrical signal to an optical signal, was set to negative.

3. Measurements of a 60-ps pulse

An impulse signal generator manufactured by PicoSecond Pulse Lab was borrowed from SLAC. The impulse produced by this signal generator has a rising time, T_r, of 54 ps (10–90%), and a falling time, T_f, of 42 ps , as shown in Fig. 10. Therefore, the bandwidth of the signal ranges from $0.5/_{T_r}$,which is 9.3 GHz, to $0.5/T_f$, which is 12 GHz. The frequency bandwidth of the oscilloscope must be at least 1.4 times the frequency bandwidth of the signal. Therefore, the scope should have a bandwidth of 17 GHz to measure both the rising and the falling edges.

Fig. 10. The overlapped original signal (front) and measured signal (back).

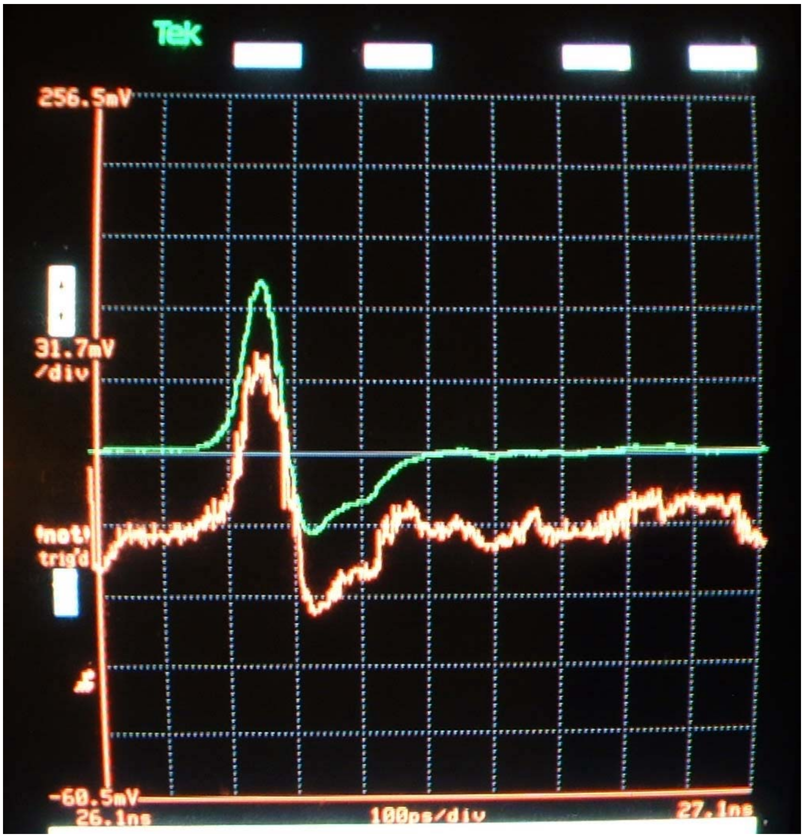

Fig. 11. The measured signal (bottom) and the original signal (top).

The signal was measured (a) directly with TEK 11801C with sampling head SD-24 (20 GHz frequency response), as a repetitive signal, and (b) with YY Labs' Fiber Loop Single-Shot Scope, as a single shot, in conjunction with the TEK 11801C. Fig. 10, taken directly from the sampling scope, shows the overlapped signals from the original and from the Fiber Loop Single-Shot Scope. Fig. 11 shows the corresponding separate displays. The two pictures reveal that the measured signal very closely matches the original signal.

Acknowledgements

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