

BEAM DIAGNOSTICS WITH OPTICAL-FIBER OPTICS

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Abstract

Optical fiber has been widely used for communications. It is a waveguide with very high-frequency bandwidth. Therefore, it has broad applications for high-frequency related signals such as high-energy Accelerator beam signals. Research, developments and field-tests have been done to measure charged particle beam and synchrotron radiation with optical fiber based instruments developed by the author.

INTRODUCTION

Optical fiber may be considered as a waveguide with very wide frequency bandwidth and a very high-frequency response. The regular single-mode fiber has core size of only 9 μm . The frequency response is specified as 100 GHz/km. With dispersion compensation, the transmission distance can be very great. The development of the fiber-optics in recent years has provided us with many optical-fiber components, such as splitter, combiner, circulator, variable attenuator, and others, which are the blocks for us to build fiber optical circuits easily.

A Department of Energy SBIR grant was received to develop a device based on fiber-optics to measure single-shot very short pulses. The device captures a single-shot, then regenerates it in an optical-fiber recirculating loop to produce a pulse train, and a sampling scope can recover the original signal from the pulse train. Figure 1 explains the principle of the sampling oscilloscope. The whole system works as a high-frequency real-time scope, for the prototype, it goes to 20-GHz bandwidth, which is much higher than the real-time scope available on the market, and potentially, it can go even higher. Tests have been done with SLAC accelerator beams and with 60-ps pulses produced by Pico-second Pulse Lab's Impulse signal generator [1]. A US patent has been issued for this technology [2].

The real-time scopes on the market are using fast digitizing, and DSP technique mathematically to expand the frequency response [3], which is a complete different technique from what the single-shot fiber-loop instrument utilizes. Since the original single-shot is regenerated to form a pulse train, with sequential sampling method of the sampling scope to recover the original signal, the resolution, therefore, is determined by the sampling scope and the system noise. The equivalent sampling rate can be calculated. If we use

20 ps/div, the sampling scope samples 512 points for the total frame. The equivalent sampling rate is $512 / 200 \times 10^{-12} = 2560 \text{ GS/sec}$, which is 100 times higher than the commercially available 20-GS/s.

INSTRUMENT

Optical-fiber Recirculating loop has been used in communication field to study the signal transmission. The communication uses digital signals, the recirculating loops for digital signals are completely different from the one built by YY Labs, which is an analogue application. An effort has been made to reduce noises, to maintain the fidelity of the signal [4]. A 2-km fiber loop is used. 3000 circulations have been achieved. Each turn has been studied and compared individually (see Figure 2 and 3.)

Figure 2 and Figure 3 show the 100th and 1000th circulation of a reference signal circulating in the optical fiber loop.

The optical circuits of the instrument can also be considered as a storage ring. An optical-fiber amplifier in the ring will compensate the energy loss of the signal due to the split of the signal of each circulation, and the loss of the optical components. The fiber amplifier also becomes the major noise source due to its Amplified Spontaneous Emission (ASE). The optical-fiber loop could become a fiber-laser if its gain is larger than 1, and the circulation cannot maintain if the gain is smaller than 1. The Erbium-fiber-amplifier has been specially designed to minimize the noise figure. Filters have been used to reduce the ASE. Acoustic modulators are used as variable attenuators and switches, with an electronics feedback system to keep the fiber-loop system gain equal to 1. The Figure 4 shows the two-channel pulse train generator, the Figure 5 shows the instrument, which is named Single-shot scope.

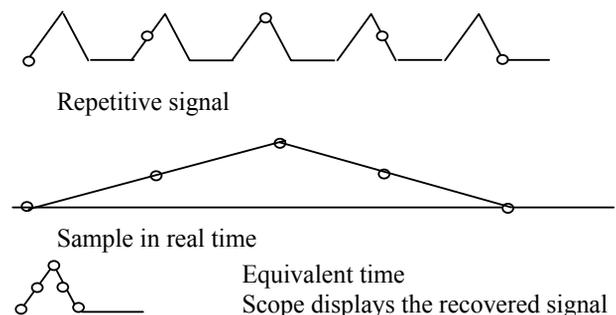


Figure 1. Sampling Principle

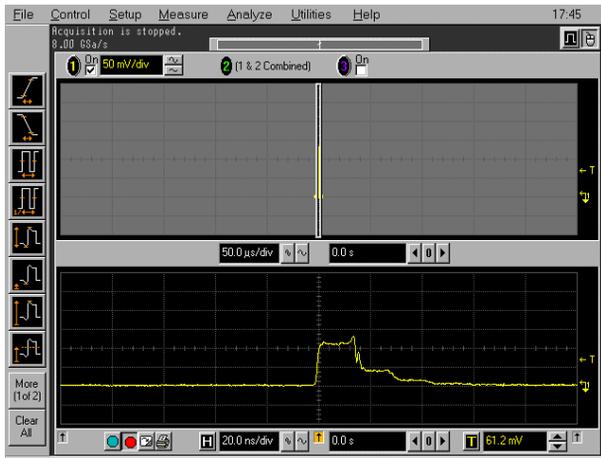


Figure 2: The 100th circulation

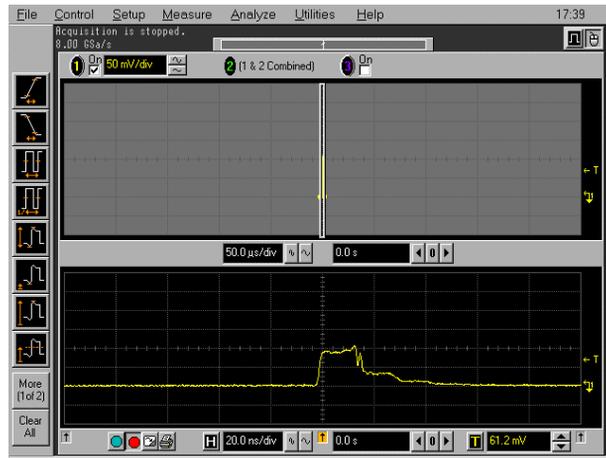


Figure 3: The 1000th circulation

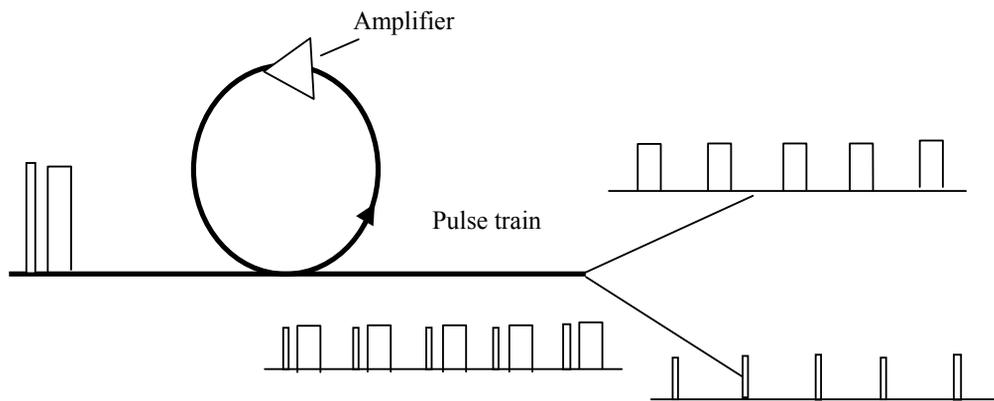


Figure 4. Two-Channel Pulse Train Generator



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Figure 5: YY Labs' Single-shot scope based on fiber-optics

The advantage of using this method is to use low-speed electronics together with fiber optics other than the difficult high-speed digitizing technique to accomplish the challenge of the signal measurements

with 20-GHz or even higher frequency response. The cost of the instrument is much lower than a regular real-time oscilloscope of this frequency band. Potentially this instrument can go up to 40-GHz by

only replacing an electro-optical modulator without changing electronics. This technique does not use any mathematic approach to increase the frequency response.

The optical-fiber technology has other applications in the accelerator field, such as to deliver the high-frequency signals to various places for control and display purposes due to its immunity from electromagnetic interference and also much more economy than the expensive high-frequency electrical cables. Optical transceivers have been highly developed in recent years, and the prices of them are coming down in large scale due to fiercely competition.

Many special fiber-optic components have been developed these years, such as fiber-arrays, collimators with fiber already attached for collecting light into the fiber. Many new monitors can be developed based on these new components.

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REFERENCES

1. Yin, Yan, and *etl.*, "Multichannel single-shot transient signal measurements with a fiber delay line loop" in *Nuclear Instruments & Methods in Physics Research A*, 517 (2004) 343-348.
2. Yan Yin, US patent 6,738,133 B1 on May 18, 2004 on "Method and device for measuring single-shot transient signals".
3. John Pickerd, "DSP in high performance oscilloscope," www.tektronix.com
4. Yin, Yan, and *etl.*, "A Multichannel 20-GHz Real-Time Scope Based On Optical- Fiber Delay-Line Loop Technology," 2004, APOC 5625-158
5. <http://www.YYLabs.com>.