High Resolution Optical Sampling Oscilloscope of 1 THz

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An epoch-making optical sampling oscilloscope has been developed by considering the optical-optical sampling method with low repetition sampling. It becomes possible to measure an optical waveform and evaluate an eye diagram up to 1 THz (1ps). The principle of optical-optical sampling is also described.

Keywords: optical sampling oscilloscope

In optical fiber communications, for example, OTDM (Optical Time Division Multiplex) requires a high bit-rate above 40 Gbps. If a bit rate exceeds 10 Gbps, it will become necessary to measure a waveform because of nonlinear phenomena influence. To this end, usually, we use the combination instruments of a high-speed optical-electro conversion equipment and a high-speed electric oscilloscope. However, it is difficult to measure the waveform of a signal above 40 Gbps using these equipments, since we have frequency characteristic restrictions in electric circuits and devices.

In order to overcome these difficulties, an optical sampling oscilloscope has been developed by taking into account the optical-optical sampling method with low repetition sampling. This optical sampling oscilloscope is an epoch-making equipment since we can measure an optical waveform and evaluate an eye diagram up to 1 THz (1ps).

Using this optical sampling oscilloscope, the waveform of 160 Gbps data signal is observed. Figure 1 shows the standard measurement of photonic network for a 48 Gbps bit error rate measurement system and a 160 Gbps signal waveform observation system.

The principle and time chart schematics of optical-optical sampling are illustrated in Fig. 2.

The sampling pulse light of the low repetition frequency fs is prepared to the clock frequency fo of a measured signal.

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\frac{1}{f_s} - n / f_s = \Delta T \quad \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots 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frequency-restrictions of an optical receiver or an electric circuit by setting low frequency $f_s$.

The actual time resolution of optical - optical sampling is determined by the pulse width and a jitter of sampling pulse.

The one of the advantages of this method is the sequential sampling. At the conventional random-sampling system, it is difficult to measure the pattern synchronization. On the other hand, since this sampling is performed sequentially, it is possible to measure the pattern signal.

A clock frequency is needed to change by user with his field. For example, at 10GHz field, 10.66GHz is used to the submarine system, but 9.95328GHz is used to the land system. In view of this example, about clock frequency, it is necessary to measure by carrying out variable by the resolution to a 10kHz digit.

Then, we investigate the method of various clock signal. The system is explained as below:

A synchronization with $f_0$ and $f_s$ needs in the above-mentioned principle. In the 1st prototype of an optical sampling oscilloscope, the basic clock signal was supplied from DUT(Device Under Test) with a measured light, and the sampling clock $f_s$ was generated by down-converting this $f_0$. Since the down-conversion ratio for generating $n$ and $f_s$ in Equation (1) could take only the integer, we can not realize $\Delta T$ corresponding to unique $f_0$. Furthermore, the down-converter with low jitter and variable ratio is also difficult to design, so the ratio is set constant after all. In this case, $\Delta T$ depends on $f_0$, so when $f_0$ is changed, they will also change $\Delta T$.

The block diagram of a new optical sampling oscilloscope, in which the problem is solved and clock variable measurement is realized, is shown in Fig. 3.

First, the reference clock of a synthesizer (10MHz in this figure) is connected to DUT in Fig. 3). By using origin oscillator of an optical sampling oscilloscope also for DUT, the synchronization with the signal inside the optical sampling oscilloscope and $f_0$ is established. Next, the value of $f_0$ and $\Delta T$ is inputted to an optical sampling oscilloscope. The $f_s$ value, which is calculated from Equation (1) based on this $f_0$ and $\Delta T$, is set as a synthesizer.

In this structure, the range of clock frequency is 4GHz to 500GHz at intervals of 10kHz. Although it can set up in the wider range theoretically, it is restricted for some reasons, such as the frequency response of detector block, pulse width of sampling light, and the jitters of internal synthesizer.

Furthermore, by this system, a low jitter can be measured theoretically. Each sampling is done according to the repetition frequency $f_s$ of sampling pulse light, so a fixed relation between the number of repetitions (equal to the number of sampling times) and the sampling position in a measured signal is kept. This relation is explained in Fig. 4.

In this figure, when a sampling start position set 0, the sampling position in the number of times $n$ of a sampling is expressed as a position delayed by the product of $n$ and $\Delta T$ from the start position. In the same way, the number of sampling times delayed by one cycle of a clock frequency can be calculated. After all, since the $m$-th sampling position calculated by the equation

$$1 / f_0 = m \times \Delta T$$

is in agreement with a sampling start position in a measured signal, it sets this position as the sampling start position for the next measurement. Thus, a sampling start position and a position in agreement appear for every multiple of $m$.

In this system, a jitter of an optical sampling oscilloscope is only dependent on the jitter of a synthesizer, so it can be sampled by a low jitter.

From the above principle, a noble optical sampling oscilloscope has been developed. In the near future, a bit-rate will be accelerated with 80 Gbps, 160 Gbps and more, then this optical sampling oscilloscope will be very useful.

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