

# Laser coherence measurement based on optical pulses interference

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By using a feedback-stabilized fiber Mach-Zehnder interferometer (MZI) with a PZT-based phase shifter, a novel method for measurement of laser coherence length is demonstrated based on pulses interference. Experimental results show that the coherence length is closed to that measured by the commercial optical spectrometer, and the partial coherence phenomenon is observed. Our scheme can measure not only the high-coherence laser but also low-coherence pulses, which is widely used in coherent laser measurement and application.

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Laser coherence is an important characteristic which plays a key role in many fields such as optical coherent control, communication, and sensing<sup>[1-3]</sup>. In general, the coherence length of the laser can be roughly evaluated by using a commercial optical spectrometer. However, the spectrometers usually has a limited resolution of several picometers (pms), for example, the resolution is 10 pm for AQ6317C. It is not enough to measure the laser high-coherence lasers with coherence length of several decimeters and even meters. Moreover, optical spectrometer provides only the results in frequency domain, not any one in time domain, let alone to further study on partial coherence phenomena.

In this letter, we propose a new method to measure the laser coherence based on time-domain optical pulses interference, and experimentally demonstrate its performance and observe the partial coherence phenomenon, while the results are further compared with that of the optical spectrometer.

Assume the optical field of two pulses with relative delay  $\Delta l$  can be described by the super-Gaussian function as<sup>[4]</sup>

$$E_1(t) = \exp \left[ -\frac{\ln 2}{2} \left( 2 \frac{t}{\text{FWHM}} \right)^{2m} \right] \cdot \exp[-i(\omega t + \phi_1)], \quad (1)$$

$$E_2(t) = \exp \left[ -\frac{\ln 2}{2} \left( 2 \frac{t + \Delta l/v}{\text{FWHM}} \right)^{2m} \right] \cdot \exp[-i(\omega(t + \Delta l/v) + \phi_2)], \quad (2)$$

where  $v$  is the light speed in the optical fiber,  $\omega$  and  $t$  are the frequency and time,  $\phi_1$  and  $\phi_2$  are the initial phases, FWHM is full-width at half-maximum of the pulse, and  $m$  is the positive integer.

Theoretically, when two above pulses will interfere constructively if  $\Delta l$  is shorter than coherence length, which is shown in Fig. 1.

The total intensity of the overlapped optical pulses is<sup>[5]</sup>

$$I = I_1 + I_2 + 2\sqrt{I_1 I_2} \text{Re}\gamma_{12}(\tau),$$

$$\begin{cases} |\gamma_{12}| = 1, & \text{completely coherent} \\ 0 < |\gamma_{12}| < 1, & \text{partially coherent} \\ |\gamma_{12}| = 0, & \text{completely incoherent} \end{cases} \quad (3)$$

where  $\gamma_{12}(\tau)$  is plural periodic function of  $\tau$ . The intensity of the overlapped part is changed with the phase difference ( $\Delta\phi$ ). For  $\Delta\phi=0$  and  $I_1 = I_2$ , the overlapped amplitude is four times of the original pulses, while it decreases to zero for  $\Delta\phi=\pi$ . When the delay between two pulses becomes much longer than the coherence length, the overlapped amplitude is two times of the original pulses, that is the completely deconstructive interference.

The experimental setup for optical pulses interference is shown in Fig. 2. The optical pulses source consists of a

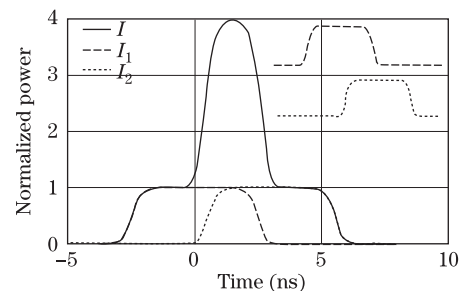


Fig. 1. Interference pattern of optical pulses.

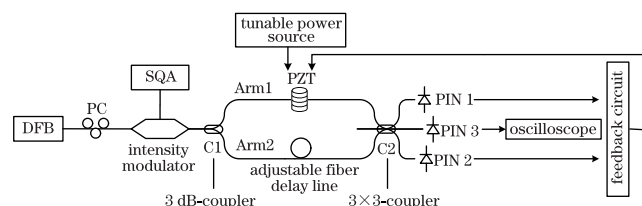


Fig. 2. Experimental setup for interference of optical pulses.

coherent laser source ( $\lambda=1556.353$  nm), followed by an intensity modulator<sup>[6]</sup>. Driven by a signal quality analyzer (SQA), the modulator generates a non-return-to-zero (NRZ) super-Gaussian optical pulse train with data rate up to 12.5 Gb/s<sup>[7]</sup>. And then the optical pulses are split into two equal parts by a fiber Mach-Zehnder interferometer (MZI). In Arm2 of the MZI, a tunable fiber delay line is used to separate the pulses. While the delayed pulses interfere in the  $3\times 3$  coupler ( $C_2$ ), and the interference waveforms are displayed by an oscilloscope<sup>[8]</sup>. To obtain the constructive and deconstructive interference, a PZT-based phase shifter is inserted in Arm1 and a tunable power source is employed to finely adjust the phase difference ( $\Delta\phi$ ) between two arms of the MZI.

Nevertheless, the MZI structure is sensitive to the fluctuation of temperature and vibration, so the interference waveforms are not stable in natural environment. As shown in Fig. 3(a), the amplitude of the overlapped part presents random fluctuation after a sudden disturbance. In order to solve the problem, a feedback circuit is designed to drive the PZT for stabilization of the phase shift  $\Delta\phi$ <sup>[9]</sup>. The whole feedback device is also composed of two photodiodes PIN1 and PIN2, which transform the optical signals to electric signals. After this improvement, the interference waveforms become very stable. Figure 3(b) shows the results with feedback stabilization, from which we can find that the interference waveform of the pulses remains highly stable after less than one second following the same sudden disturbance.

In our experiment, the SQA is set to generate electric signals at 10 Gb/s. In order to observe the interference of optical pulses, we edit the electric signal pattern for different fiber delays. The measured results are plotted in Fig. 4. Figure 4(a) shows the waveform for delay of 20 cm. Since  $I_{\min}$  is about 0 and  $I_{\max}$  is about four times of the original pulse's, the delayed pulses are coherent which means the coherence length of the laser is at least 20 cm. Further measurement for delay of 20.5 cm

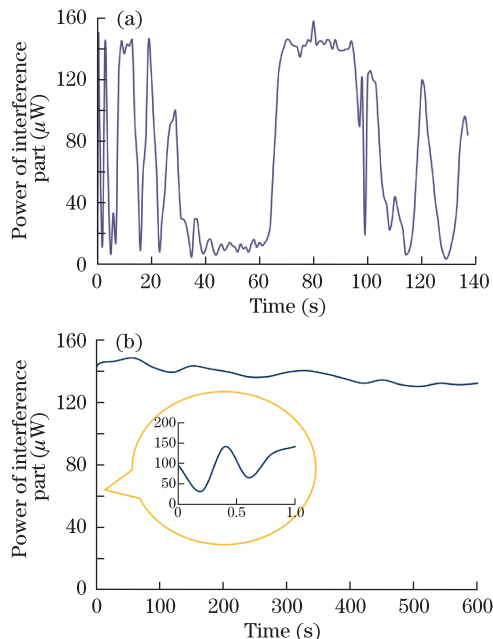


Fig. 3. Power of the interference part of the pulses after a sudden disturbance (a) without feedback and (b) with feedback.

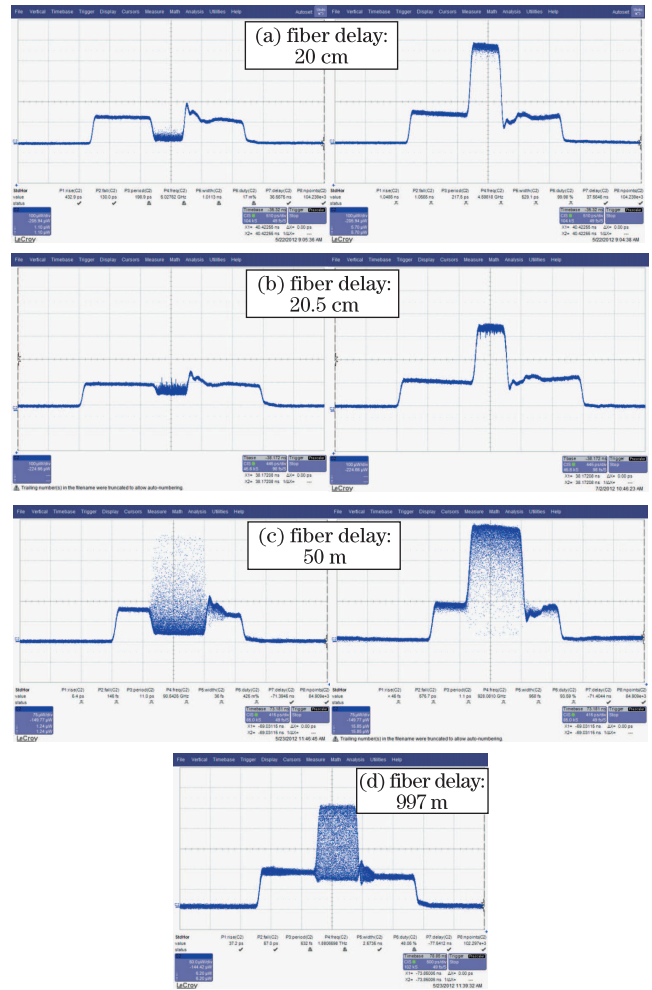


Fig. 4. Interference pattern of optical pulses in different fiber delay lengths. (a)  $\Delta l=20$  cm, (b)  $\Delta l=20.5$  cm, (c)  $\Delta l=50$  m, and (d)  $\Delta l=997$  m.

shows that the pulses become partially coherent as illustrated in Fig. 4(b), therefore the coherence length of the laser is between 20 and 20.5 cm<sup>[10]</sup>.

Moreover, we measure the pulse interference for longer delays such as 50 m and even 997 m. The results are illustrated in Figs. 4(c) and (d). For 50-m delay, we find that the overlapped amplitude still change when  $\Delta\phi$  varies but  $I_{\min}$  does not equal zero and  $I_{\max}$  is less than four times of the original one, which can be seen clearly in Fig. 4(c). However, when the fiber delay is 997 m, the waveform is very stable when the phase difference changes as shown in Fig. 4(d). From above results, we can deduce that, when the fiber delay is much longer, the pulses become completely incoherent, and the amplitudes of overlapped part decrease to two times of the original pulse.

In addition, we measure the optical spectrum of the laser as shown in Fig. 5, where the center wavelength ( $\lambda_c$ ) is 1556.353 nm and spectral width ( $\Delta\lambda$ ) is 0.014 nm. So the theoretical value of this laser coherence length ( $l_c=\lambda_c^2/\Delta\lambda$ ) is 17.3 cm, which is closed to the result measured by pulses interference.

It is worth to mention that the measurement resolution is determined by the adjustable minimum fiber delay. In

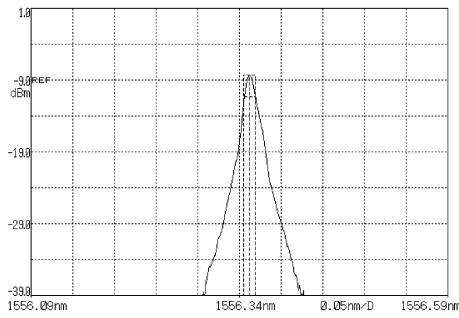


Fig. 5. Optical spectrum of the laser in our experiment.

our experiment, the tunable fiber delay line can be improved to a PZT driven one, that is, the resolution will be micrometer even nanometer magnitude, which can obtain precisely the coherence length. And it can be also employed to measure the low coherent laser pulses.

In conclusion, a novel method for measurement of laser coherence length is presented and demonstrated based on pulses interference in a feedback-stabilized fiber MZI with a PZT-based phase shifter. The results show that the measured coherence length is closed to that done by the optical spectrometer, and the partial coherence of the laser pulses is observed in the experiment. Our scheme can measure not only the high-coherence laser but also low-coherence pulses, which paves the way for accurate

coherence measurement.

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