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The measurement of propagation delay in multimode optical fibre with pulse-reflection-oscillation method

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Abstract

Using the pulse-reflection-oscillation method, a high precision optical fibre propagation delay measurement system is made and applied to measure multimode optical patchcords of four different lengths (10, 20, 50 and 100 m). The result shows that the standard deviation is less than 11 ps.

Keywords: Fibre length measurement; Fibre group delay measurement; Fibre break locator

1. Introduction

The measurement of the time delay of light propagation in an optical fibre can be used not only for the determination of the length of the fibre [1,2] but also for the detection of the break point in the fibre [3,4]. The variation of delay of light propagation in a fibre due to external forces caused by temperature change, pressure change or stress [5–8] can be used for the estimation of the fibre strain. Traditionally, there are two common methods used to measure the delay of light propagation in an optical fibre: One is the pulse method, and the other is the phase-shift method. The former employs time-delay cables and sampling oscilloscopes, while the latter employs precision phase meter and stable multi-frequency oscillators. In either method, careful adjustment and calibration procedures are needed in order to obtain high-accuracy data. The expensive and huge instruments employed in both the methods make the in-field measurement impossible. They can be applied only in laboratories.

The transit-time oscillation method (TTO) [9,10] is shown in Fig. 1. The start pulse initiates a closed-loop square-wave oscillator composed of the optical fibre, transmitter, receiver and electronic circuit. The frequency of oscillation is inversely proportional to the optical fibre delay, the opto-electronic component delay, and the electronic delay in the circuitry. The propagation delay of light propagated in fibre can be obtained through frequency measurement, therefore this method only has to employ simple equipment. However, the disadvantage regarding this method is that the two ends of the fibre must be contacted. For a fibre that is already installed in a communication system, it is impossible to contact the far end of the fibre. Therefore, The application of the TTO is limited. In this paper, we present a so-called pulse-reflection-oscillation method (PRO). Its principle is similar to the TTO. The difference is that the PRO uses the Fresnel signal reflected from the fibre end as the triggering signal, while the TTO uses the transmitted signal as the triggering signal. The advantage of the PRO is its simple circuit and its employment of only one fibre end for contact. PRO can be used in in-field applications. PRO is more convenient for use than other methods.

2. System description

Fig. 2 shows the block diagram of a PRO system. When one pushes push button (PB) manually, the Trig1 port of the pulse generator is triggered. Pulses of ECL level and 10 ns duration are generated. The transmitter (constructed from laser diode and current-driven circuit) converts the

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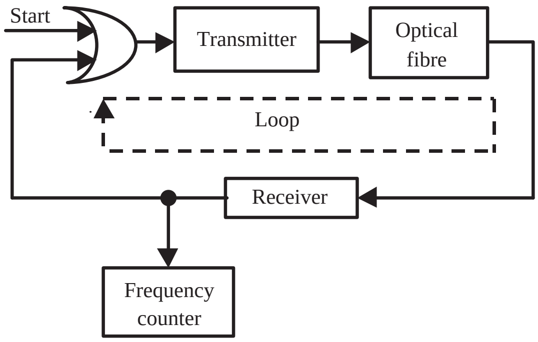

Fig. 1. Schematic of the transmit time oscillation method.

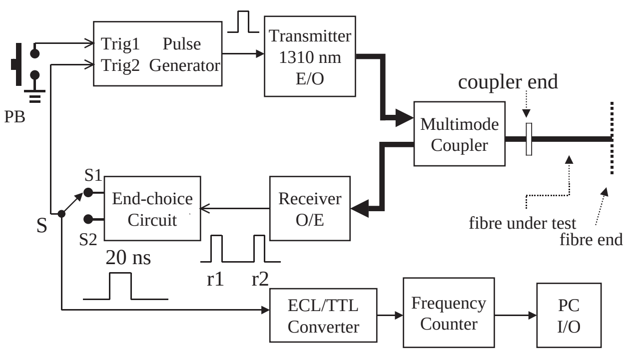

Fig. 2. Fibre propagation delay measurement system with PRO.

pulses into light pulses of optical wavelength 1310 nm. The multimode coupler (of the ratio 50:50), on the one hand, couples the light pulses coming from the transmitter to the fibre for measurement. On the other hand, it couples the Fresnel reflection light coming from the fibre end to the receiver, which consists of a PIN detector, a transimpedance preamplifier and a postamp, and outputs electrical signals of ECL level. An end-choice circuit is designed for distinguishing the light reflected on the coupler end from that reflected on the fibre end. The pulse $r1$ is the reflected pulse from the coupler end. The pulse $r2$ is the reflected pulse from the fibre end. The output signal (pulse of 20 ns) triggers the Trig2 port of the pulse generator to produce a closed-loop oscillation. The computer reads the data of the frequency-counter through its I/O port and converts the data into oscillation period, T:

$$T = T_{sys} + T_{fib} = T_{sys} + 2NL/C, \quad (1)$$

where T_{sys} is the time delay of propagation of the system. It represents the sum of the time delay due to each component in the system, including electronic components, coupler, laser, PIN, etc. T_{fib} is the time delay of propagation in the fibre under test. L is the length of the optical fibre, N is the index of refraction of the optical fibre, and C is the speed of light in vacuum.

When the fibre is not connected, we switch the end-choice circuit to S_1 to let the coupler-end-reflection signal pass. We measure the time delay of propagation under this condition, T_{sys}. We then connect the fibre for measurement and switch the end-choice circuit to S_2 to let the fibre-end-reflection signal pass. We measure the time delay of propagation under this condition, T. The time delay due to the fibre, T_{fib}, is $T_{fib} = T - T_{sys}$.

3. Experiment and results

We took multimode optical fibre pathcords of four different lengths (shown in Table 1) for measurement. The experiments were carried out after 30 min of warming up, with the room temperature of 25°C. In order to investigate the repeatability and the drift of the system performance, the measurement was taken 5400 times, or 3 h, for each case of applying one fibre to the system. Each measurement took 2 s, with 1 s for frequency counting and the other second for data-acquisition and oscillation period-calculation in the computer. Table 1 shows measurement results regarding the average oscillation period and the standard deviation. From the table it can be seen that the maximum standard deviation is 10.7 ps, which was obtained when we measured the fibre of 50 m. The similar measurement process with no fibre applied yields a standard deviation of 5.1 ps.

Fig. 3 is the histogram for the measurement of multimode fibres of four different lengths. Each fibre was measured for 5400 times. The histogram shows the distribution of the frequency counts. The abscissa is class interval, with one interval being equal to one standard deviation. The ordinate is counts per interval. From the figure it can be seen that almost 85% of the measurement data for the four fibres fall in ±1.5 standard deviations. Only few data fall in the interval from −3.5 to −2.5 standard deviations. There are 33 such data regarding the 10 m fibre and 52 such data regarding the 20 m fibre. For all these fibres, the maximum deviation is less than 26.75 ps, which is equivalent to 2.5 standard deviation regarding the 50 m fibre.

Fig. 4 shows the drift of the measurement results regarding the fibres of four different lengths. In the figure, each point stands for the average of 150 successive measurement data. In other words, the average is calculated every 5 min. For 5400 data, 36 averaged values are obtained. From the figure, it can be seen that the maximum drift is 20.5 ps, which occurs at the 70-min point regarding the 50 m fibre.

Table 1
Averages and standard deviations of 5400 measurements on each fibre patchcord

Fibre patchcord	Length (cm)	Average, oscillation period (ns)	Standard deviation (ps)
No fibre	0	41.682	5.1
T10 m	1,029.1	144.558	7.5
T20 m	2,019.1	243.260	7.5
T50 m	5,058.2	546.460	10.7
T100 m	10,006.2	1,041.362	10.5

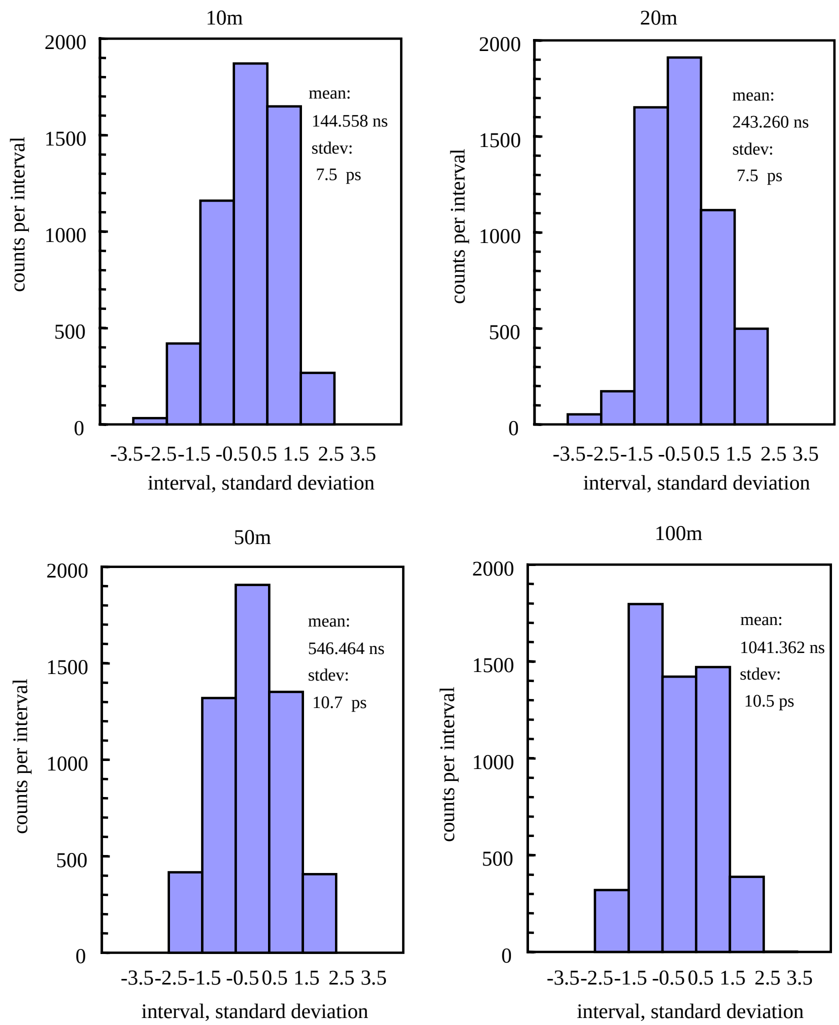

Fig. 3. The histogram of 5400 measurements for multimode fibre of four different lengths.

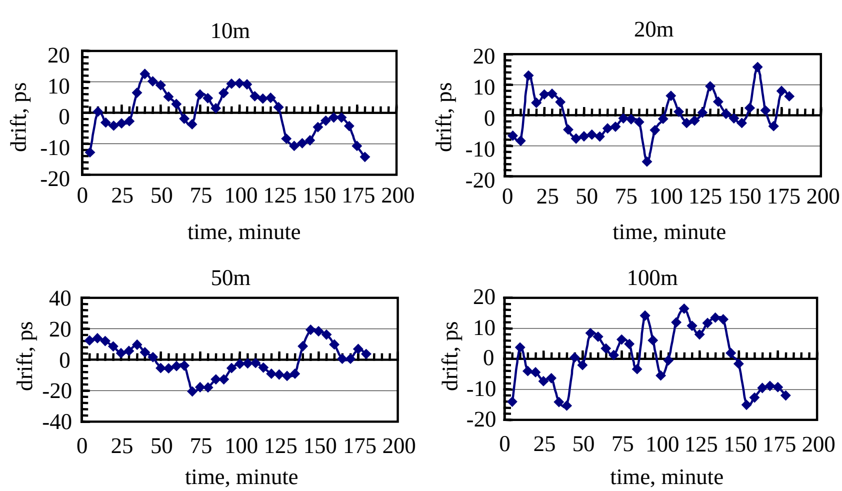

Fig. 4. The drift of measurements for multimode fibre of four different lengths.

4. Conclusion

In this paper, it is shown that the PRO method can achieve very good performance of high precision, even though the noise suppression and the cooling treatment of the universal printed circuit board have not been done yet. The effect of fibre length causes standard deviation not larger than 11 ps. The high precision, the simple circuit, and the simplicity of employing only one fibre-end contact indicate that, for time-delay measurement of light propagation in a fibre, the PRO method is a practical convenient method for in-field application.

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