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Dispersion parameter and fiber length measurements technique over multi-wavelength bands

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Abstract

We demonstrate a simultaneous measurements technique of the fiber length and the dispersion parameter by using low-cost Fabry-Perot lasers. It enables us to measure the dispersion parameter over multiple wavelength bands at the same time.

1 Introduction

The measurements of the dispersion parameter and the length of an optical fiber have become more important since the up-to-date high-capacity transmission systems employing the dispersion management and the distributed amplification techniques require accurate values of the dispersion parameter and the length. The measurements of the dispersion parameter and the length are usually performed independently using different instruments. Various measurement techniques have been developed for the dispersion measurement while optical-time-domain-reflectometry (OTDR) is dominantly used for the length measurement [1-2].

We have demonstrated a simultaneous measurements technique of the dispersion parameter and the fiber length by using a low-cost Fabry-Perot laser diode (F-P LD) to decrease the measurement cost and the time required[3-5]. However, the measurement wavelength range of the previous technique is limited by the gain spectra of the F-P LD and can not exceed several tens nm. In this paper, we demonstrate a novel measurement technique to expand the measurement wavelength range to several wavelength bands, namely, up to several hundreds nm.

2 Operation principle

Fig. 1 shows the schematic diagram of the proposed measurement system. It is arranged to form an optical closed-loop composed of the C- and the L-band F-P LDs, a wavelength-division multiplexer (WDM), an optical circulator and a fiber-under-test (FUT). Each F-P LD is pre-biased and the modulation currents generated by the signal generator are also applied to both LDs.

The F-P LDs emit multi-mode optical pulse train and the outputs are re-injected into the LDs after traveling the optical close-loop. We assume either of the F-P LDs emits three modes (λ_1, λ_2, λ_3) for the simplicity. The pulses of different modes generated by either of the LDs depart the LD at the same time and synchronize with the applied current. However, the chromatic dispersion of the FUT causes a round-trip time difference (ΔT_D) between the pulses as shown in Fig. 2(a). The time difference is given by $\Delta T_D = DL\Delta\lambda$, where D is the dispersion parameter of FUT, L is the length of FUT and $\Delta\lambda$ is the wavelength difference between the modes.

If a specific mode pulse (λ_2) arrives at the moment when the current applied to F-P LD is higher than the threshold current, a laser oscillation occurs only at the mode (λ_2). Similarly, the laser oscillation may occur at one of the other modes (λ_1) if the modulation frequency is changed so that the pulse of a specific mode (λ_1) is re-injected to the F-P LD at the moment when the applied current is higher than the threshold current, as shown in Fig. 2(b). If the relative time deviation (ΔT_{MD}) due to the modulation frequency change (ΔF_{MD}) is given by $\Delta T_{MD} \approx nL\Delta F_{MD}/cF$, where n is the refractive index of FUT, c is the velocity of light in vacuum and F is the initial modulation frequency. We can change the lasing mode from one to another if the time deviation due to the frequency change (ΔF_{MD}) is equal to the round-trip time deviation (ΔT_D) between the modes. Thus, the dispersion parameter of the FUT is given by[3]

$$D = -\frac{n}{cF}\frac{\Delta F_{MD}}{\Delta\lambda} \qquad (1)$$

The laser oscillation may occur at the specific mode (λ_2) again if the pulse arrival time of the mode satisfies the condition shown in Fig. 2(c). Assume that the self-seeding laser oscillation occurs at the λ_2 mode when the modulation frequency is F and the minimum frequency change required to induce the laser oscillation at the λ_2 mode again is ΔF_{ML}. The round-trip time of the optical pulse is nL/c and should be equal to N/F to induce the laser oscillation at the λ_2 when the modulation frequency is F, where N is an integer. It also should be equal to $(N+1)/(F+\Delta F_{ML})$ if the modulation frequency is changed to $F+\Delta F_{ML}$ to induce the lasing at the same λ_2 mode again. From this, the length of FUT is given by[4]

$$L = \frac{c}{n\Delta F_{ML}} \qquad (2)$$

By using the Eq. (1) and the Eq. (2) we can calculate the dispersion parameter and the length of the FUT if measure the required frequency changes, the ΔF_{MD} and the ΔF_{ML}. We can use a direct lasing mode detection technique to measure them[6]. Since a self-seeding laser oscillation occurs at a specific mode, the total output power through the close-loop increases compared with the case without the laser oscillation, which caused an output power fluctuation when the modulation frequency is swept continuously. We could detect the lasing mode from the fluctuation by using a photo-detector and a signal processor as shown in Fig. 1.

It is notable that the F-P LDs are coupled with WDM and operate independently and thus we can use several LDs with different gain spectra. This means that we can measure the dispersion parameters over multi-wavelength bans at the same time by using multiple F-P LDs with different gain peaks.

3 Experimental results

To confirm the performance of the proposed system, we measured the dispersion and the length of the standard single mode fiber (SMF) by using conventional C- and L-band F-P LDs. The mode-spacings ($\Delta\lambda$) of the LDs was about 0.8 nm and the center wavelengths of the LDs were 1552.5 nm and 1591.1 nm, respectively.

Fig. 3(a) shows the output of the photo-detector when we sweep the modulation frequency from 500 MHz to higher. It fluctuates with the modulation frequency and the self-seeding laser oscillations occur at the local peaks. In the C-band, the frequency change required to repeat a lasing at the same mode was 187.79 kHz and the calculated length of FUT by using the eq. (2) was 1.085 km. Also, the frequency change was 187.65 kHz and the calculated length was 1.086 km in the L-band. The relative measurement error compared with the length measured with a commercial OTDR (Anritsu, MW9060A) was less than 0.36 % in both cases.

We measured the frequency changes (ΔF_{MD}) for different wavelengths from the outputs of photo-detectors shown in Fig 3(a) and calculated the dispersion parameters using eq. (1). The measurement results are shown in Fig. 3(b) and we also show the dispersion measurement results by using a commercial instrument (PerkinElmer, FD440) to examine the accuracy of the proposed technique. Two results agree well and the relative measurement error was less than 2.8 % over C- and L-band wavelength ranges. We also measured the dispersion parameters and the lengths of optical fibers with different lengths. The results were very similar but the measurable wavelength range slightly decreased for longer fibers.

In summary, a simultaneous measurements technique of the dispersion parameter and the fiber length over multi-wavelength bands has been demonstrated by using the self-seeding laser oscillation of the F-P LDs and the direct lasing mode detection technique. The relative measurement errors compared with the commercial instruments were less than 0.36 % for length and 2.8 % for dispersion parameter measurements. It is notable that we can easily expand the multiple-band wavelength range by using multiple F-P LDs.

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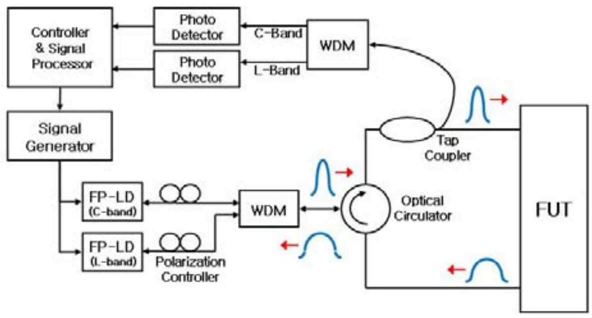


Fig. 1. The schematic diagram of the proposed measurement system

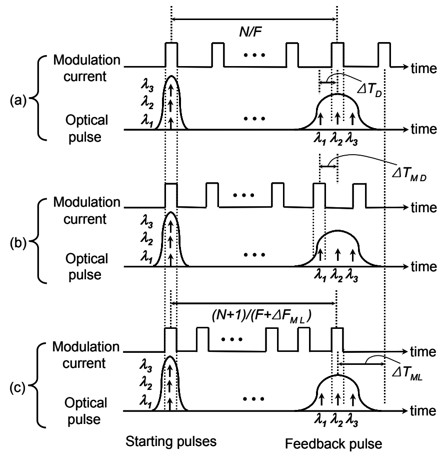
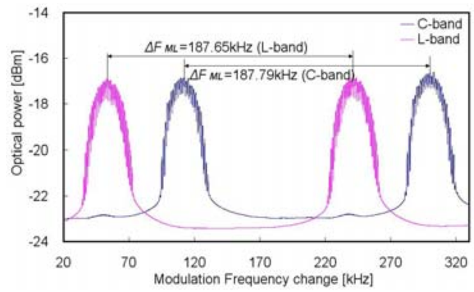
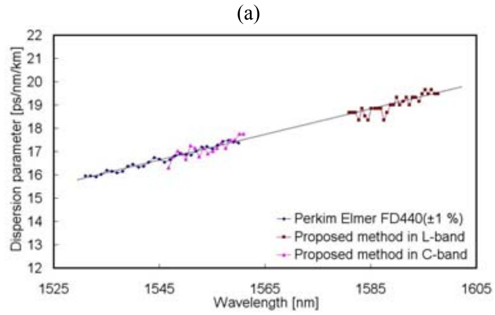


Fig. 2. Time diagrams of applied current and optical pulse, (a) when the modulation frequency is F, (b) $F + \Delta F_{MD}$ and (c) $F + \Delta F_{ML}$



(a)



(b)

Fig. 3. The outputs of the photo-detector for different modulation frequencies (a) and the measured dispersion parameters (b)