Chromatic dispersion monitoring technique using birefringent fiber loop

Yuen-Ching Ku, Chun-Kit Chan, Lian-Kuan Chen
Department of Information Engineering, The Chinese University of Hong Kong, Shatin, N.T., Hong Kong SAR.
ycku2@ie.cuhk.edu.hk

Abstract: A chromatic dispersion monitoring technique using birefringent fiber loop is proposed. An unambiguous measurement range of 1500-ps/nm for 10-Gb/s NRZ signal is demonstrated without transmitter modification. This technique can be used to monitor multiple channels.

OCIS codes: (060.2330) Fiber optics communications; (260.2030) Dispersion;

1. Introduction

Chromatic dispersion (CD) is one of the major signal impairments in optical transmission systems. It is due to the fact that light different frequencies travel at different speed inside fiber. CD causes pulse spreading and intersymbol interference (ISI) which would severely degrade transmission performance. To adaptively compensate CD, CD monitoring is required to provide feedback control. Several CD monitoring techniques have been proposed. One of the approaches is to measure dispersion by observing the fading of added RF tones [1]. However, modification of transmitter is required, which may not be always possible. Also, the added RF tones would degrade the transmitted signal. Another similar technique, but without modification at transmitter side, is to monitoring the regenerated clock in NRZ signals and faded clock in RZ signals under dispersion [2]. However, this technique is modulation format and bit-rate dependent. Comparing the phases of optically filtered spectral components [3] is a highly sensitive approach to measure CD. However, it requires fast electronics if the data rate is high.

In this paper, we propose and demonstrate a new technique for monitoring dispersion using birefringent fiber loop (BFL). By feeding a signal distorted by chromatic dispersion into a fiber loop which consists a high-birefringence (Hi-Bi) fiber, the dispersion experienced by the signal can be deduced from the measured RF power at a specific selected frequency which is determined by the length of the Hi-Bi Fiber. This technique requires no modification at the transmitter, and provides large measurement range that is independent of data rate. CD monitoring by the proposed technique was experimentally demonstrated. A measurement range of 1500 ps/nm can be achieved for 10-Gb/s NRZ signal.

2. Proposed chromatic dispersion monitoring module using birefringent fiber loop

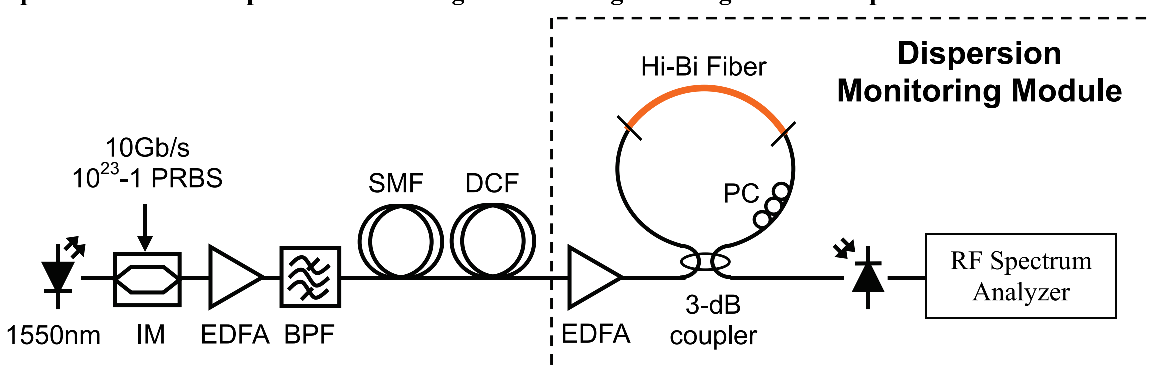

Fig. 1. Schematic diagram of the proposed chromatic dispersion monitoring module, with experimental setup for demonstration. IM: intensity modulator, EDFA: erbium-doped fiber amplifier, BPF: optical bandpass filter, SMF: single-mode fiber, DCF: dispersion compensating fiber, PC: polarization controller

As an intensity-modulated double side band signal transmitted along a fiber, dispersion will convert some of the intensity modulated signal into phase modulation, giving phase delay φ_f at frequency *f* as a result of expansion in a power series of the frequency dependent propagation constant $\beta(\omega)$ due to chromatic dispersion [4]. Since φ_f changes with dispersion, the total accumulated dispersion *D* of the fiber link can be determined by measuring the phase modulation at a specific spectral component. This can be easily accomplished by a birefringent fiber loop (BFL) which only consists of a 3-dB coupler, polarization controller (PC) and high-birefringence (Hi-Bi) fiber [5] as shown in Fig.1. The advantages of using BFL include simplicity, polarization insensitivity and low insertion loss.

The incoming signal is split by the 3-dB coupler into two counter-propagating beams that would recombine and interfere at the coupler after traveling around the fiber loop. The clockwise (CW) and counter-clockwise (CCW) beams would experience a time delay τ induced by the Hi-Bi fiber under the condition that the PC inside the loop provides a 90^o rotation for beams from both directions. Considering the carrier ω_0 and sidebands $\omega_0 \pm \Omega$, the RF power at $\Omega = \pi / \tau$ can be expressed as [6]:

$$P \propto \sin^2\left(\frac{\varphi_\Omega + \varphi_{-\Omega}}{2}\right) = \sin^2\left(\frac{\pi\lambda^2 f_{RF}{}^2}{2} D\right) \tag{1}$$

where λ is the optical wavelength, $f_{RF} = \Omega / 2\pi = 1/2\tau$, and c is the speed of light in vacuum. Therefore, by measuring the RF power of the detected signal from the BFL at f_{RF} using an RF spectrum analyzer, the total accumulated dispersion can be determined.

The monitoring position f_{RF} can be easily adjusted by varying τ which is controlled by the length of the Hi-Bi fiber. This gives a freedom of control to system administrator for optimizing the measurement range and stability. In general, the measurable D increases with the decrease of f_{RF} which can be easily observed from equation (1). However, a long Hi-Bi fiber is needed which may degrade the stability. Note that in practice a bandpass filter together with an RF power meter can be used to replace the RF spectrum analyzer. Also, multiple channels monitoring can be realized if the channel spaces are tuned to be $\Delta\omega = q\pi/(2\tau)$ where q is an integer.

3. Experiment and results

The proposed CD monitoring technique was experimentally demonstrated in a 10-Gb/s NRZ on-off keying (OOK) system, as shown in Fig. 1. The signal source was a tunable laser at 1550 nm, externally modulated by a LiNbO3 optical intensity modulator with 10-Gb/s 2^{23}-1 PRBS NRZ data. The modulated signal was amplified by an EDFA, before transmitting through a dispersive link which consists of different combinations of single-mode fiber (SMF) or dispersion-compensating fiber (DCF) to produce different amount of accumulated dispersion. The signal is then sent to the proposed dispersion monitoring module.

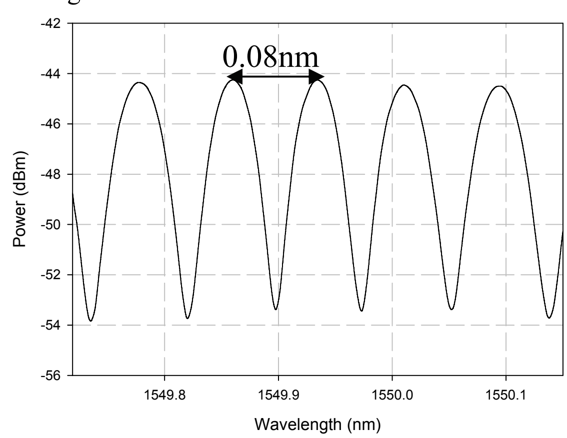

Fig. 2. Transmittance of the birefringent fiber loop.

The dispersion monitoring module consists of an EDFA, a BFL, a 20GHz detector and an RF spectrum analyzer. The EDFA is used to maintain the same optical power at the detector to ensure that the measured power variations are caused by dispersion, not a change in received optical power. The BFL consists of a 3-dB coupler, a PC, and a segment of Hi-Bi fiber with a birefringence of 5.275×10^{-4}. The Hi-Bi fiber was put in metal box and temperature controlled. The relative optical delay between the two axes of the Hi-Bi fiber is about 100 ps (length=56.8m), which was verified by observing the peak spacing in the BFL transmittance as shown in Fig. 2. The received power at 5 GHz ($f_{RF} = 1/2\tau$) was measured using an RF spectrum analyzer with a 1-MHz measurement bandwidth.

Fig. 3 shows the RF spectra for accumulated dispersion of 0 ps/nm, 110 ps/nm, and 450 ps/nm respectively. It can be seen that the received RF power at 5 GHz varies in different cases. Therefore the power variation can be used as an index indicating how much accumulated dispersion has been experienced by the signal. Fig. 4 shows the measured RF power at 5 GHz for different values of accumulated dispersion. An unambiguous measurement range of 1500 ps/nm was observed using the proposed CD monitoring technique. Note that in principle the measurement range can reach $c/(2\lambda^2 f_{RF}{}^2)$ = 2497ps/nm for λ=1550nm, independent of data rate and modulation format [6]. Nevertheless, accumulated dispersion only up to 1500 ps/nm was measured in our experiment due to the lack of equipment availability. The proposed technique can be further modified to determine the dispersion sign, with the use of similar technique demonstrated in [7].

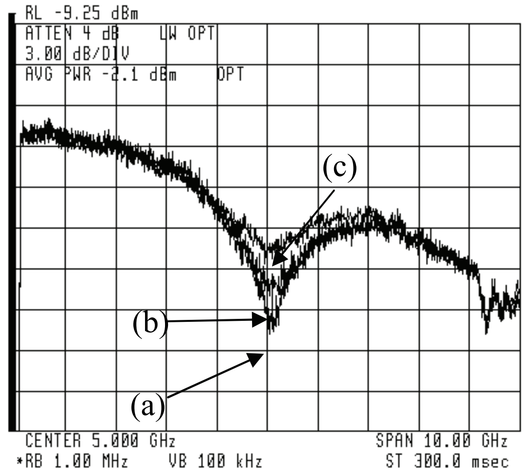

Fig. 3. RF spectrum at BFL output for signals with (a) 0 ps/nm, (b) 110 ps/nm and (c) 450 ps/nm accumulated dispersion

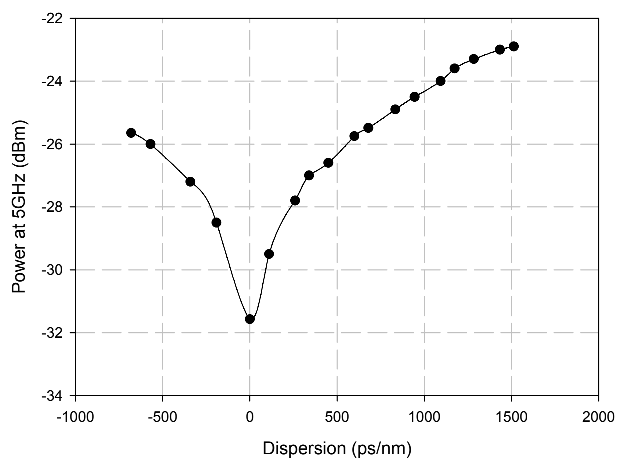

Fig. 4. Received RF power at 5GHz as a function of dispersion

4. Summary

In this paper, a new chromatic dispersion monitoring technique using birefringent fiber loop without transmitter-side modification was proposed and demonstrated. Experimental results showed unambiguous measurement range of 1500 ps/nm for 10-Gb/s NRZ data. The measurement range is tunable, and independent of data-rate/modulation format, by adjusting the length of BFL. This work was partially supported by a grant from the Research Grants Council of Hong Kong SAR, China.

References

[1] G. Rossi, et. al., "Optical Performance Monitoring in Reconfigurable WDM Optical Networks Using Subcarrier Multiplexing," IEEE JLT **18**, 1639-1648 (2000)

[2] Z. Pan, et. al., "Chromatic dispersion monitoring and automated compensation for NRZ and RZ dada using clock regeneration and fading without adding signalling," in Proc. OFC (2001)

[3] Q. Yu, et. al., "Chromatic Dispersion Monitoring Technique Using Sideband Optical Filtering and Clock Phase-Shift Detection," IEEE JLT, **20**, 2267-2271 (2002)

[4] H. Schmuck, "Comparison of optical millimetre-wave system concepts with regard to chromatic dispersion," IEEE EL, **31**, 1848-1849 (1995)

[5] C. W. Chow, et. al., "Polarization-Independent DPSK Demodulation Using a Birefringent Fiber Loop," IEEE PTL, **17**, 1313-1315 (2005)

[6] A.L. Campillo, "Chromatic Dispersion-Monitoring Technique Based on Phase-Sensitive Detection," IEEE PTL, **17**, 1241-1243 (2005)

[7] S. Wielandy, et. al., "Real time measurement of accumulated chromatic dispersion for automatic dispersion compensation," IEEE EL, **38**, 1198-1199 (2002)