Optical Fiber Technology 19 (2013) 319–324

Contents lists available at SciVerse ScienceDirect

Optical Fiber Technology

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# A new method for fiber chromatic dispersion measurement with microwave interference effect

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ARTICLE INFO

*Article history:*
Received 21 August 2012
Revised 29 November 2012
Available online 6 May 2013

*Keywords:*
Optical fiber
Chromatic dispersion
Microwave photonics
Microwave interference effect

ABSTRACT

The chromatic dispersion (CD) is a key parameter for optical fibers. Based on the microwave interference effect, a new method for CD measurement of optical fibers is proposed. The radio frequency (RF) signals carried by two light-waves with different wavelengths transmit through the dispersive optical fiber under test. After photo-detector they interfere with each other due to the different phase shifts induced by the CD of fiber. The CD can be obtained by monitoring the changing interference RF power with scanning the wavelength of tunable laser source. The CD values of single mode fiber and dispersion compensating fiber are measured within the wavelength range from 1525 to 1605 nm. The common phase shift method is used to measure the CDs of the two types of fiber, which demonstrates the feasibility and veracity of the proposed method.



## 1. Introduction

Among fundamental parameters of optical fibers, the chromatic dispersion (CD) is a critical one, which restricts the performance of long-haul optical fiber communication system with high data rate and radio over fiber transmission system with high RF frequency [1–5]. A variety of techniques have been used for measuring the CD of optical fibers, most of which are based on phase-shift method, pulse-delay method, or optical interferometric method [7–9]. Recently, several novel approaches for CD measurement utilizing microwave photonic techniques have also been proposed [10–16]. The CD can be determined by measuring relative group delay through the frequency spectrum range (FSR) of microwave notch filter [10]; however, the accuracy is susceptible to the environmental conditions that add different phase noises to the reference path and the test path. CD can also be obtained with precise measurement by the phase to intensity modulation conversion [11]; however, the wavelength of the light source and the frequency of the modulation microwave have to be scanned respectively if the CD in a large light-wave range is needed. The coherent heterodyne detection which down converts the spectrum of digitally modulated signal from optical domain to RF domain has been used for CD monitoring [12]. Improvements have been made to the method by measuring the power of clock tones that are down converted to very low frequencies to avoid extra costs from expensive electronic devices [13]. The RF power spectrum [14] and RF clock power ratio with optical notch filter [15,16] have been proposed and demonstrated to CD monitoring for high speed optical transmission systems.

In this paper, we propose a novel and simple method to measure the CD of optical fibers by utilizing the microwave interference effect. The CD can be obtained by monitoring the changing interference RF power, which varies with the scanning wavelength of the tunable laser source (TLS). The CD values of single mode fiber (SMF) and dispersion compensating fiber (DCF) are measured within the wavelength range from 1525 to 1605 nm. To verify the validity of the method, the common phase shift method [6,7] is used to measure the CDs of the two types of fiber. The influence of RF frequency on the measurable data points and data processing and how to distinguish the sign of the CD are analyzed.

## 2. Principle and system architecture

The RF signal carried by the light-wave in the optical fiber experiences phase shift. Due to the CD of the optical fiber, the phase shifts of RF signals with the same frequency carried by two light-waves are different. The RF signals interference with each other when they are recovered by the photo-detector (PD) [17]. Fig. 1 shows the schematic diagram of our proposed CD measurement system. Light-waves from the two lasers, one with a fixed wavelength $\lambda_1$ and the other with a tunable wavelength $\lambda_2$, are coupled into an electro-optic Mach–Zehnder modulator (MZM) through an optical coupler, and the amplitudes of the two lasers are simultaneously modulated by the same RF signal with frequency $f_{RF}$ and initial phase $\varphi_0$. The modulated light-waves transmit through the fiber under test (FUT).

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1068-5200/$ - see front matter 
http://dx.doi.org/10.1016/j.yofte.2013.03.005

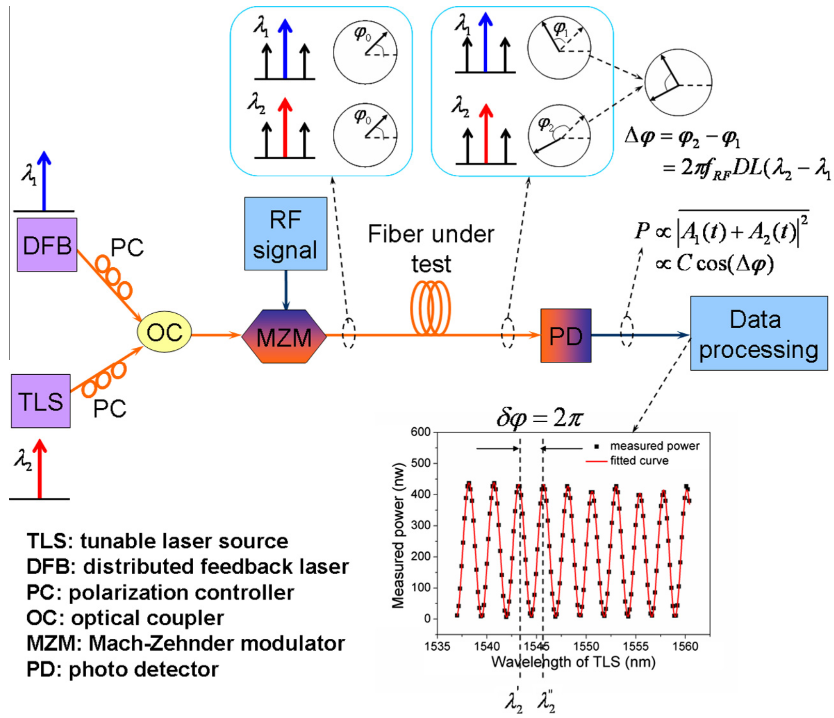


**Fig. 1.** Schematic diagram of the experimental setup for CD measurement.

Due to the incoherent phase noise of each light source, the beating at PD only occurs between two sidebands of the same optical carrier [17]. For the convenience of understanding the microwave interference, the two RF signals carried by the two light-waves respectively detected by the PD can be expressed as [18,19]

$$A_1(t) \propto A_{10}\cos\left(\frac{\pi DL f_{RF}^2 \lambda_1^2}{c}\right)\cos(2\pi f_{RF} t + \varphi_0 + \varphi_1) \tag{1}$$

$$A_2(t) \propto A_{20}\cos\left(\frac{\pi DL f_{RF}^2 \lambda_2^2}{c}\right)\cos(2\pi f_{RF} t + \varphi_0 + \varphi_2) \tag{2}$$

where $A_{10}$ and $A_{20}$ are the amplitudes of the two RF signals, $DL$ the total CD value (ps/nm) of the optical fiber, $c$ the speed of light in vacuum, and $\varphi_1$ and $\varphi_2$ are the phase shifts of the RF signals through the optical fiber.

The values of $A_{10}$ and $A_{20}$ can be set to the same amplitude $A_{10} = A_{20} = A_0$ in the measurement process by adjusting the output power of the laser source (TLS and DFB), which facilitates achieving high extinction ratio of the interference curve. Then the RF power after the PD can be expressed as

$$P \propto \overline{|A_1(t) + A_2(t)|^2} \propto A_0^2\cos^2\left(\frac{\pi DL f_{RF}^2 \lambda_1^2}{c}\right) + A_0^2\cos^2\left(\frac{\pi DL f_{RF}^2 \lambda_2^2}{c}\right) + 2A_0^2\cos\left(\frac{\pi DL f_{RF}^2 \lambda_1^2}{c}\right)\cos\left(\frac{\pi DL f_{RF}^2 \lambda_2^2}{c}\right)\cos(\Delta\varphi) \tag{3}$$

where $\Delta\varphi = \varphi_2 - \varphi_1$ is the phase difference between the two light-wave carried RF signals induced by the optical fiber. This can be written as

$$\Delta\varphi = \omega_{RF}\Delta\tau = 2\pi f_{RF}\Delta\tau \tag{4}$$

where $\Delta\tau$ is the group time delay difference between the two RF signals and is generated by the two light-waves in the optical fiber. It can be expressed as [20]

$$\Delta\tau = DL\Delta\lambda \tag{5}$$

where $\Delta\lambda = \lambda_2 - \lambda_1$ is the wavelength difference of the two light-waves. According to Eqs. (4) and (5), the phase difference between the two light-wave carried RF signals in the proposed measurement system can be expressed as

$$\Delta\varphi = 2\pi f_{RF} DL(\lambda_2 - \lambda_1) = \Delta\varphi_0 + \delta\varphi \tag{6}$$

where $\Delta\varphi_0 = 2\pi f_{RF} DL(\lambda_{20} - \lambda_1)$, $\delta\varphi = 2\pi f_{RF} DL\delta\lambda_2$, $\lambda_2 = \lambda_{20} + \delta\lambda_2$, $\lambda_{20}$ and $\delta\lambda_2$ are the initial wavelength and the scanning wavelength range of the TLS, respectively. From Eq. (3), we can see that the received RF power changes periodically with $\delta\lambda_2$ (also shown as the inset in Fig. 1), and the total CD value can be achieved by

$$DL = \frac{\delta\varphi}{2\pi f_{RF}\delta\lambda_2} \tag{7}$$

When the received RF power varies one period, namely from one maximum to the adjacent maximum, the phase separation $\delta\varphi$ becomes equal to $2\pi$. The total CD can be calculated by Eq. (7) with the wavelength scanning range $\delta\lambda_2$.

## 3. Experimental results

A proof-of-concept experiment was implemented based on the configuration as shown in Fig. 1. The experiment setup consisted of a TLS (Agilent 81600B) with tuning range of 1525–1605 nm, a DFB (Emcore-1772) with center wavelength 1550 nm, an MZM (Covega Mach-LN™ 058) with bandwidth of 20 GHz, and a PD with bandwidth of 40 GHz ($u^2t$ 2120R). The RF signals at different frequencies were generated by a signal generator (Agilent 8267D). The RF signal power was monitored by a microwave power meter. The LABVIEW platform was applied to collect data of the scanned wavelength of TLS and the obtained interference RF signal power. In the experiment, the optical power of the DFB and TLS were both set to 6 dBm. The wavelength $\lambda_2$ of the TLS was scanned from 1525 to 1605 nm. The CD of a 25-km SMF and a 200-m DCF available in our laboratory were measured, respectively.