

In-Line Chromatic Dispersion Measurement for NRZ and RZ Signals Using a Novel RF Spectrum Phase Detection Technique

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ABSTRACT

In this paper, a novel method of in-line chromatic dispersion (CD) measurement is proposed, we theoretically and experimentally demonstrated the CD measurement of 10-Gbit/s NRZ and RZ signals by a novel RF spectrum phase detection technique, this is performed using in-band tone monitoring RF, electrically down-converted to direct current (DC) or a low intermediate-frequency (IF) of less than 1MHz through electronic mixing with local oscillator (LO) of 2.4 GHz. The measurement provides a large CD measuring range with good accuracies ($\pm 2000 \pm 35$ ps/nm), and independent of the bit-rate and data format. In addition, the use of electronic mixer and low-speed detectors makes it cost effective for in-line CD measurement.

Keywords: Radio Frequency Photonics; Frequency Modulation; Fiber Measurements; Fiber Optics Links; Subsystems; Modulation; Ultrafast Processes in Fibers

1. Introduction

With the increased demand for large data capacity, higher data rates have become an essential requirement of next generation light-wave system. It has been recognized that at data rates higher than 10 Gb/s, it will be necessary to provide tunable dispersion compensators (TDC) in order to accommodate uncertainties and dynamic chromatic dispersion (CD) variations in link, various tunable dispersion compensators have been demonstrated [1]. For such devices to be working effectively, an appropriate residual CD measuring and feedback signal must be obtained from the data stream passing through the TDC. Various feedback signals are possible including, bit-error rate (BER) derived from forward error correction algorithms, eye monitoring e.g [2], and schemes that rely on monitoring the RF spectrum of the detected bit stream after a fast photo-detector e.g [3], but these feedback signals can't indicate the value of residual CD, and it is necessary to adjust TDC till obtain a perfect state of feedback signals, that need a lot of time for adjusting, if residual CD value changed, the process must be iterated.

So some researchers have focused on researching of residual CD monitoring, and there have been several ap-

proaches of CD monitoring recently demonstrated, including asynchronous sampling and histogram evaluation [4-8], electrical dispersion equalizer [9], self-phase modulation, four-wave mixing, and cross-phase modulation (XPM) in optical fibers [10-12], radio-frequency (RF) tone measurement [13,14]. However, some of these approaches tends to require either high-speed components (e.g., oscilloscope, detector, RF spectrum analyzer, or analog-to-digital converter), a tunable DLI to decode phase information into amplitudes, or high data input power.

2. Principle of CD Measurement

The model of this technique is depicted in **Figure 1**. This technique is based on electrical mixing with orthogonal I-Q procedure.

The incoming signal $E_{DSB}(t)$ is a modulated dual sideband (DSB) signal, two single sideband (SSB) tunable band-pass optical filter is used to distill upper and lower sideband of the incoming signal, that the upper sideband signal and lower sideband signal are respectively given by:

$$E_L(t) = \alpha\sqrt{I_0} \cos(\omega_0 t) + \beta\sqrt{I_0} \cos((\omega_0 - \omega_d)t + \varphi_L), \quad (1)$$

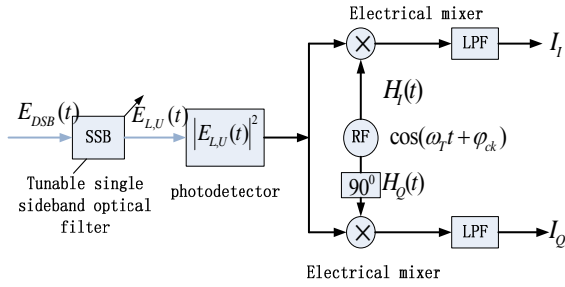


Figure 1. Principle of CD measurement based on RF spectrum phase detection using electrical mixing.

$$E_U(t) = \alpha\sqrt{I_0} \cos(\omega_0 t) + \beta\sqrt{I_0} \cos((\omega_0 + \omega_d)t + \varphi_U). \quad (2)$$

After the photo-detector and the electrical mixing, the in-phase and in-quadrature received signals $I_{I,Q}$ for the LSB and USB are given by:

$$I_{IU} = |E_U(t)|^2 \times H_I(t), \quad (3)$$

$$I_{QU} = |E_U(t)|^2 \times H_Q(t), \quad (4)$$

$$I_{IL} = |E_L(t)|^2 \times H_I(t), \quad (5)$$

$$I_{QL} = |E_L(t)|^2 \times H_Q(t), \quad (6)$$

where $H_I(t)$ and $H_Q(t)$ are the electrical mixer transfer functions for the in-phase and in-quadrature signals $I_{I,Q}$, respectively given by:

$$H_I(t) = \cos(\omega_r t + \varphi_{ck}), \quad (7)$$

$$H_Q(t) = \cos\left(\omega_r t + \varphi_{ck} + \frac{\pi}{2}\right) \quad (8)$$

where ω_r is the RF modulation frequency of the LO signal and the φ_{ck} is its relative phase to the data clock.

When $\omega_r = \omega_d$, the detected signals I_{IU} , I_{IL} , I_{QL} , I_{QU} after low pass filter (LPF) are determined from Equations (9)-(12)

$$I_{IL} = \frac{\alpha\beta I_0}{2} \cos(\varphi_L + \varphi_{ck}), \quad (9)$$

$$I_{QL} = \frac{\alpha\beta I_0}{2} \cos\left(\varphi_L + \varphi_{ck} + \frac{\pi}{2}\right), \quad (10)$$

$$I_{IU} = \frac{\alpha\beta I_0}{2} \cos(\varphi_U + \varphi_{ck}), \quad (11)$$

$$I_{QU} = \frac{\alpha\beta I_0}{2} \cos\left(\varphi_U + \varphi_{ck} + \frac{\pi}{2}\right), \quad (12)$$

The relative phase of the carrier and each sideband for the LSB and USB (φ_L and φ_U) are given by:

$$\varphi_L = \text{Arctg}\left(\frac{I_{QL}}{I_{IL}}\right) - \varphi_{ck}, \quad (13)$$

$$\varphi_U = \text{Arctg}\left(\frac{I_{QU}}{I_{IU}}\right) - \varphi_{ck}. \quad (14)$$

It is noted that the phase difference $\Delta\varphi$ is independent of LO signal's phase φ_{ck} , and $\Delta\varphi$ is given by:

$$\Delta\varphi = \varphi_U - \varphi_L = \text{Arctg}\left(\frac{I_{QU}}{I_{IU}}\right) - \text{Arctg}\left(\frac{I_{QL}}{I_{IL}}\right). \quad (15)$$

The GVD is then given by:

$$\text{GVD} = \frac{2\pi c \Delta\varphi}{\lambda^2 \omega_r^2}, \quad (16)$$

3. Experimental Implementation

Experimental demonstration was performed using the setup of **Figure 2**. The transmitter comprises a tunable laser (TL) operating at 1550 nm with 10MHz line width, the part of PRBS generating 10 Gbit/s pseudorandom bit sequence (PRBS), and pulse generator generates 66% NRZ and RZ pulse shape respectively, the optical carrier was modulated with a 10 GHz NRZ/RZ PRBS of length $2^{15} - 1$ through Mach-Zehnder modulator (MZM). The fiber under test (FUT) comprises single mode fiber (G.652) and dispersion compensation fiber. An erbium-doped fiber amplifier (EDFA) was used to compensate the fiber loss. At the receiver, a tunable optical band-pass filter with 3dB bandwidth of 0.6 nm was used to eliminate the redundant amplified spontaneous emission (ASE) noise, the Mach-Zehnder interferometer (MZI) with FSR (Free Spectrum Range) of 20 GHz was used to distill upper and lower signal band, the optical signal of upper and lower band were respectively detected by analog detector with 3dB bandwidth of 3 GHz, the output RF electrical signal was split into I and Q channels for mixing with local oscillator (LO), and I channel LO signal has $\pi/2$ phase difference with Q channel LO signal. In this experiment we used ADL5382 to actualize mixing RF with LO signal, the LO frequency is 2.4 GHz. The analog-digital-converters (ADC) with 14

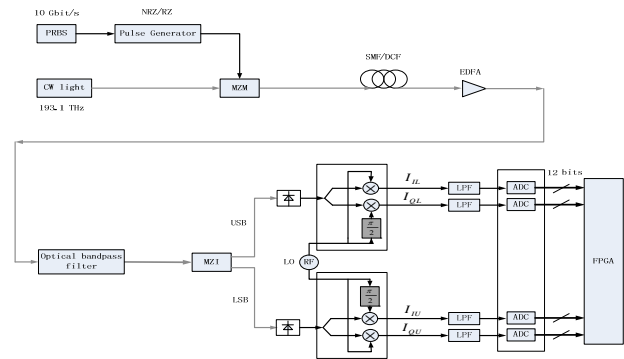


Figure 2. Experimental setup of CD measurement for NRZ and RZ systems.

bit-width and 20 MHz sample rate were used to sampling the output analog intermediate frequency (IF) signals and converting to digital signals, signals processing was performed in Field Programmable Gate Array (Xilinx: XC4VLX15).

4. Experimental Results

The positive chromatic dispersion was added to the signal using five spools of SMF of 20, 40, 60, 80, 100 km corresponding, respectively, to 335, 670, 1005, 1340 and 1675 ps/nm. The negative chromatic dispersion was added to the signal using four spools of DCF of 3, 6, 9, 12 km corresponding, respectively, to -420, -840, -1260, -1680 ps/nm. The OSNR was varied with a variable noise loading stage using an ASE source. The OSNR was maintained at a 20.5 dB level for all CD measurements. The CD measurement was tested without introducing any DGD. **Figure 3** shows the experimental results of the NRZ format signal. **Figure 4** shows the experimental results of the RZ format signal.

The precision of the dispersion measurement mainly depends on the OSNR. **Figures 5(a)** and **(b)** shows the detected phase corresponding to different OSNR under the CD of 0 ps/nm. In measurement, the result of NRZ link is more precise than RZ link under the same OSNR.

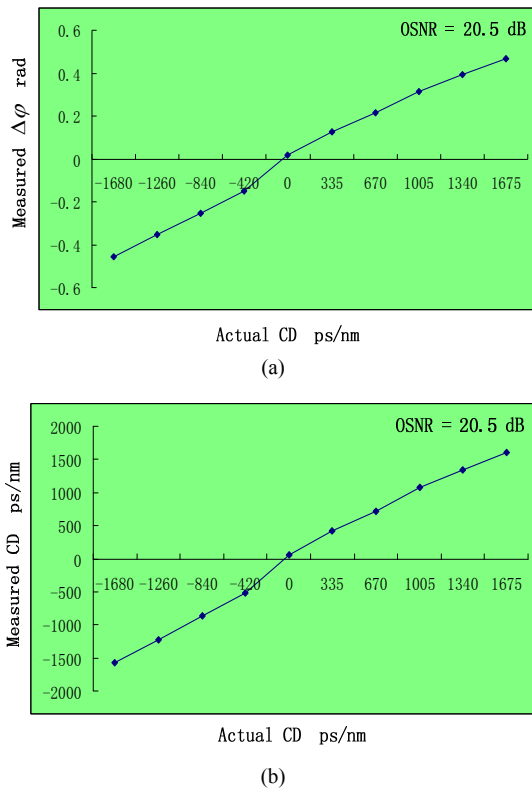


Figure 3. (a) Measured value of $\Delta\phi$ corresponding to variable CD (LO = 2.4 GHz); (b) Measured CD corresponding to actual CD (LO = 2.4 GHz).

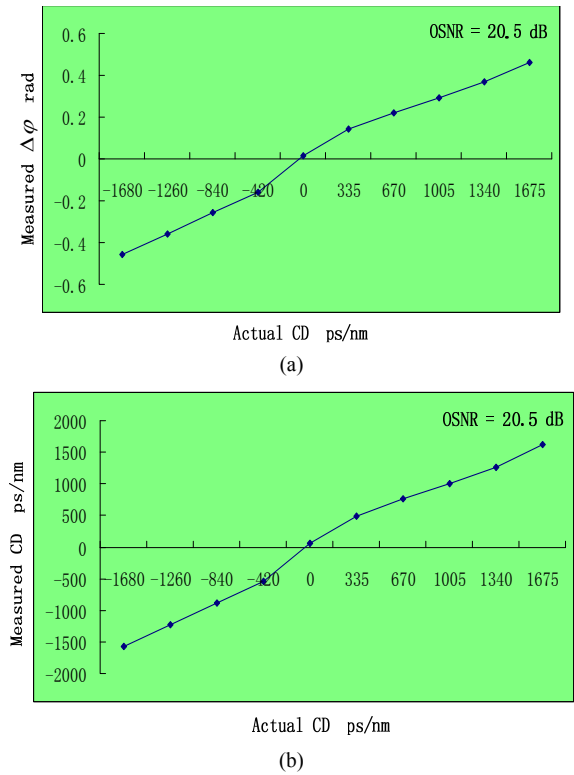


Figure 4. (a) Measured value of $\Delta\phi$ corresponding to variable CD (LO = 2.4 GHz); (b) Measured CD corresponding to actual CD (LO = 2.4 GHz).

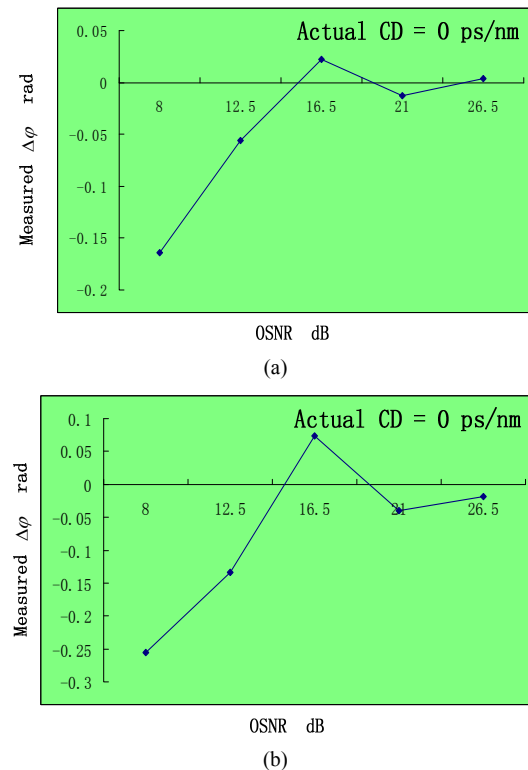


Figure 5. Detected phase corresponding to different OSNR for 10 G, (a) NRZ; (b) RZ.

5. Conclusion

In this experiment, CD measuring technique for independent of data rates and formats has been developed, the performance of the technique was experimentally and respectively assessed for 10 Gbit/s NRZ and RZ systems. The measurement range and error achieved with the proposed method, based on monitoring a 2.4 GHz in-band tone, was $\pm 2000 \pm 35$ ps/nm for CD. In condition of 2.4 GHz LO, the maximum measurement range may up to ± 9000 ps/nm, the LO is tunable that adjust it up for CD range. The technique was shown to operate in single wavelength system, it can also be used in WDM system by using a tunable optical filter (TOF) to achieve multi-wavelength channels CD measurement in serial mode, or by using array waveguide gates (AWG) to achieve all wavelength channels CD measurement in parallel mode. The minimum acquisition-time is found to be a trade-off between the required measurement accuracy and the monitoring speed. The 5 ms acquisition time, required to obtain the accuracy stated above, is suitable for measuring application in dynamic optical networks with reconfiguration times greater than that, such as ASON, OBS or OPS systems. Detuning of the MZI optical filter from the optimum position by up to 5 GHz does not have any effect on the phase measurement for the CD measuring. In addition, the use of electronic mixer for spectra down-conversion and the use of low-speed detectors make it potentially cost effective for multi-channel operation.

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