Experimental Demonstration of Resolution-Enhanced Residual Chromatic-Dispersion Monitoring Using Half-bit Delay-interferometer Filtering for RZ-OOK Systems

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Abstract *We experimentally demonstrate a residual chromatic dispersion monitoring scheme using half-bit delay interferometer with enhanced resolution of 15 (ps/nm)/dB around zero dispersion region in 10-Gb/s RZ-OOK systems, which is more suitable for adaptive dispersion post-compensation.*

Introduction

Recently, there are substantial efforts to develop real-time dispersion monitoring and adaptive dispersion-compensation techniques. This is because the chromatic dispersion of each channel could be changed frequently in dynamically reconfigurable optical networks [1]. Several techniques for monitoring chromatic dispersion and signal quality in such systems have been previously reported. One of the simplest techniques for chromatic dispersion monitoring in standard return-to-zero (RZ) and non-return-to-zero (NRZ) signals is measuring the RF power of the bit rate frequency component ("clock") after detection, as it does not require any additional modulation on the data [2,3]. Recently, based on the RF power measurement, a dispersion monitoring scheme with phase-sensitive detection using one-bit delay-interferometer has been proposed to extend the monitoring range [4]. However, the dispersion resolution is relatively poor, especially in the low dispersion range. It is not suitable for the adaptive post-compensation system, where the dispersion is monitored after tunable dispersion compensator, and the measured residual dispersion varies in low dispersion range [5].

In this paper, we experimentally demonstrate a resolution-enhanced residual chromatic dispersion monitoring scheme using half-bit delay-interferometer (HB-DI) filtering based on the RF clock-tone monitoring in a 28-ps 10-Gb/s RZ on-off-keying (RZ-OOK) system. After using an HB-DI at the end of the transmission fiber, the amplitude of the RF clock-tone is related to a sine function, rather than a cosine function, of the accumulated dispersion. Therefore, the dispersion resolution can be improved significantly around zero dispersion, which is suitable for the post-compensation.

Operation Principle

For the dispersion monitoring schemes based on the RF clock-tone monitoring, it is implemented based on the evolution of the RF spectrum of the transmission data as it propagates along a dispersive fiber. In this scheme, the detected RF power of clock tone can be expressed as [5]

$$P \propto \cos^2\left(\frac{\pi\lambda^2 DL}{c} f_c^2\right) \quad (1)$$

where f_c is RF clock tone frequency, λ is the carrier wavelength, *DL* is the total accumulated dispersion and *c* is the speed of light. It is clear that the amplitude of the clock-tone is related to a cosine function of the accumulated dispersion. It means, in the low dispersion range, the same RF power variation corresponds to large dispersion change, thus a poor dispersion resolution (defined as $\Delta DL/\Delta P$).

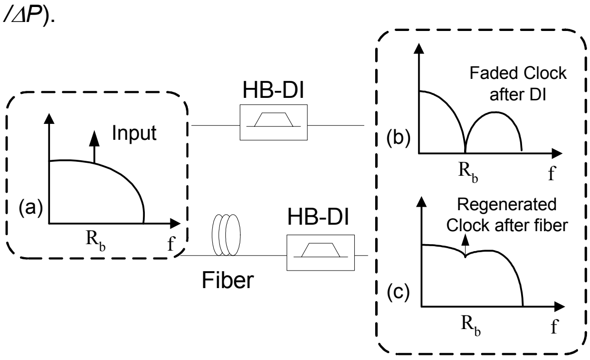

Fig. 1: Operation principle of the proposed dispersion monitoring scheme. RF spectrum of (a) input signal, signal after HB-DI (b) without and (c) with dispersion.

In our proposed scheme, as shown in Fig. 1, an HB-DI filter is used before the photo-detector after the transmission to enhance the dispersion resolution. When the HB-DI is biased at quadrature of the transmission curve, after propagation through the HB-DI, the two up/lower sidebands are out of phase if there is zero fiber dispersion. This causes power fading and nulling in the clock-tone, as shown in Fig. 1(b). With increased accumulated dispersion in the transmission link, the clock tone will regenerate (Fig.1 (c)). As a result, the RF power of the clock could be utilized as a monitoring parameter for the fiber dispersion. The behavior of clock tone's RF power with respect to the accumulated dispersion is changed as

$$P \propto \sin^2(\frac{\pi\lambda^2 DL}{c} f_c^2) \quad (2)$$

Thus, the amplitude of the RF clock-tone is now related to a sinusoidal dependence on fiber dispersion. Since the low dispersion range is shifted to the steeper part of the curve, the dispersion resolution is improved significantly around the zero-dispersion region, therefore making it suitable for post-compensation.

Experiment and Results

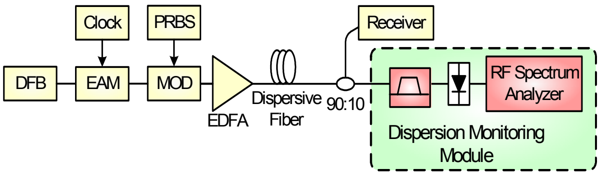

Fig. 2. Experimental setup.

The proposed monitoring scheme was experimentally demonstrated in a 28-ps 10-Gb/s RZ-OOK transmission system. As shown in Fig. 2, a CW light at 1550 nm was carved into a 10-Gb/s pulse train with a pulsewidth of 28 ps via an electroabsorption modulator (EAM), driven by a sinusoidal clock signal. The pulse train was then modulated with a 10-Gb/s NRZ pseudorandom binary sequence (PRBS) of pattern length 2^{31}-1 using a $LiNbO_3$ intensity modulator to generate a 10-Gb/s RZ-OOK optical signal. Then the signal was fed into the transmission link, where variable amounts of dispersion were provided by varying length of fiber. Some of the signal power was tapped out from the transmission link to the monitoring module. In the module, the signal first passed through an HB-DI, which is a single-ended fiber-based unbalanced Mach-Zehnder delay interferometer with a path-length difference of 50 ps (half of the bit period).

The HB-DI was biased at the quadrature point of the transmission curve by tuning its temperature. After photo-detection, the RF power of 10-GHz clock tone was measured using RF spectrum analyzer. For each transmission link with different dispersions, the optical power incident on the photo-detector was adjusted to maintain the same optical power (-5dBm) to ensure that the measured power variations were due to dispersion and not a change in received optical power. To compare the monitoring performance with the previous scheme, the control experiment without HB-DI before photo-detector was also performed.

Without HB-DI within the monitoring module, the accumulated dispersion results in the power fading of clock tone at 10 GHz. As shown in Fig. 3, the amplitude shows cosine function as accumulated dispersion. Whereas, in the proposed scheme with HB-DI, the suppressed clock tone after HB-DI is regenerated with the increase of dispersion, and the amplitude of clock tone behaviours as a sine function of dispersion. For the proposed scheme, since the low dispersion range lies at the steeper portion of the curve, the tone power is more sensitive to accumulated dispersion at low dispersion values, which is suitable for post-compensation. Compared with the previous scheme, the proposed scheme achieves the similar dynamic range of ~30 dB, and similar monitoring window of ±680 ps/nm for 10-Gb/s RZ-OOK systems. However, the dispersion resolution of the proposed scheme around zero dispersion is enhanced to 15 (ps/nm)/dB, whereas the resolution of the previous scheme is 62.5 (ps/nm)/dB.

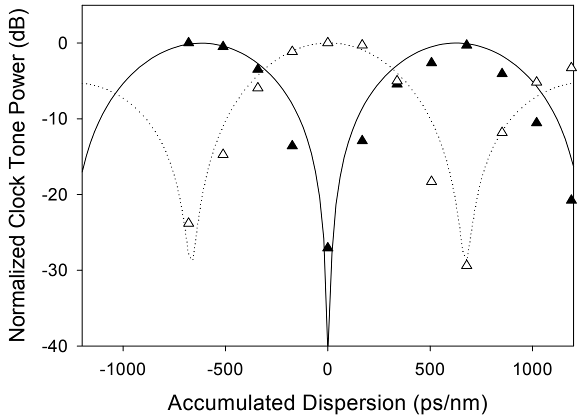

Fig. 3. Normalized RF power at 10 GHz as a function of accumulated dispersion for the previous (experiment: open symbol, simulation: dotted line) and proposed (experiment: filled symbol, simulation: solid line) schemes.

Conclusions

In the paper, we experimentally demonstrated a resolution-enhanced chromatic dispersion monitoring scheme using HB-DI filtering for RZ-OOK systems. The scheme is based on the RF power monitoring of clock tone. After HB-DI, the tone power is suppressed, and behaves as a sine function of accumulated dispersion. This shows better resolution around the zero-dispersion region, and makes it more suitable for dispersion post-compensation. The experimental results performed in a 10-Gb/s RZ-OOK system show that the dispersion resolution is significantly improved, reaching 15 (ps/nm)/dB. The project is supported in part by RGC CUHK411005 grant.

References

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