A novel scheme for automatic polarization division demultiplexing

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ABSTRACT

A novel scheme for automatic demultiplexing used the partial low frequency radio frequency (RF) power as control signals for polarization division multiplexed (PDM) system is proposed firstly. The spectrum of detected signals, which is sensitive to the angle between polarization controller (PC) and the polarization beam splitter (PBS), are thoroughly analyzed. The effectiveness of this demultiplexing method is experimentally demonstrated.

Keywords: automatic demultiplexing, PDM

1. INTRODUCTION

Polarization division multiplexing (PDM) can double the transmission efficiency of optic communication systems has attracted much attention [1,2]. Because the states of polarization (SOP) of a signal changes randomly in a transmission link, automatic polarization demultiplexing technique has to be performed to recover the two polarized signals. Compared with electronic domain demultiplexing which needs high-speed digital signal processing, the optical demultiplexing has obvious advantages. There are two categories of optical automatic demultiplexing. Including extra RF tones imposed at the transmitter using amplitude or phase modulation [3], and using different power levels for the two orthogonal signals at transmitter [4]. The obvious drawback of those mentioned methods is the increased costs caused by delicately design to impose difference between channels. In this paper, a novel scheme of automatic polarization demultiplexing is proposed.

2. DESCRIPTION OF THE THEORY

A model for a single frequency continuous wave (CW) laser electric field undergoing phase fluctuations is

$$\mathrm{E(t)}=\mathrm{E}_0 e^{j[\omega_0 t+\varphi(t)]} \tag{1}$$

Where E_0 is the amplitude of the optical field, ω_0 is the average CW carrier and $\varphi(t)$ is a stochastic process representing the random phase fluctuation leading to the broadening of spectral line.

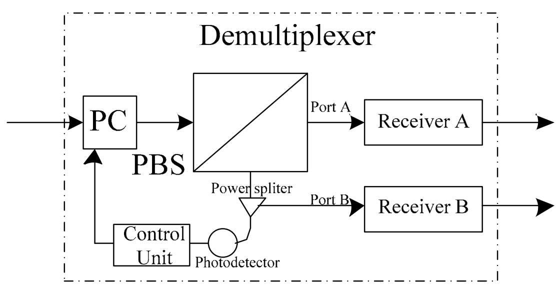

Figure 1. Demultiplexer for NRZ-OOK Polarization division multiplexing

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An automatic demultiplexer using direct detection is shown in figure 1. In PDM system, the two orthogonal signals along X axis and Y axis from the same laser but modulated with different data envelops. A polarization beam splitter (PBS) are used to demultiplex the two orthogonal signals, and the output of one receiver port can be expressed as

$$\mathrm{E_{RX}(t)}=\cos\theta \mathrm{E_{TX}}(t)e^{j[\omega_0 t+\varphi(t)]}+\sin\theta \mathrm{E_{TY}}(t)e^{j[\omega_0 t+\varphi(t+\tau_0)]} \tag{2}$$

Where $E_{TX}(t)$ and $E_{TY}(t)$ represent the modulation envelopes of the channel X and Y, respectively. θ is the angle difference between the SOP of the channel X and one port of the PBS in the Jones space. τ_0 is the differential time delay between two branches.

Because of the square law[6] of photodetector, the detection is converting the quantum phase noise of the field $E_{RX}(t)$ into intensity noise[5]. By virtue of the Wiener-Khintchine theorem, the power spectrum of the stationary field photocurrent is the Fourier transform of the autocorrelation which can be expressed as[6]

$$\mathrm{R}(\tau)=\mathrm{e}\sigma \mathrm{G_E^{(1)}}(0)\delta(\tau)+\sigma^2\mathrm{G_E^{(2)}}(\tau) \tag{3}$$

where e is the electron charge, σ is the detedtor quantum sensitivity, $G_E^{(i)}(\tau)$ is the *i*th ordor correlation function defined by

$$G_E^{(1)}(0)=\left\langle E_{RX}(t)E_{RX}^*(t)\right\rangle \tag{4}$$

$$G_E^{(2)}(\tau)=\left\langle E_{RX}(t)E_{RX}^*(t)E_{RX}(t+\tau)E_{RX}^*(t+\tau)\right\rangle \tag{5}$$

where $\langle\bullet\rangle$ denotes a time average. $e\sigma G_E^{(1)}(0)\delta(\tau)$ stands for the shot noise, since $e\sigma G_E^{(1)}(0)\delta(\tau) << \sigma^2 G_E^{(2)}(\tau)$ [5], (3) can be expressed as

$$\mathrm{R}(\tau)=\sigma^2\mathrm{G_E^{(2)}}(\tau) \tag{6}$$

We assume $E_{TX}(t)$ and $E_{TY}(t)$ are NRZ-OOK signals. Which has $\{E_{TX}(t),E_{TY}(t)\}\in\{0,1\}$ and $\left\langle E_{TX}(t)\right\rangle=\left\langle E_{TY}(t)\right\rangle=\frac{1}{2}$. By substituting (2)(5) into (6) and applying the Fourier transform, the power spectrum of the photocurrent can be obtained

$$\begin{aligned} S(\omega) &= \int_{-\infty}^{\infty} R(\tau)e^{-j\omega\tau}d\tau \approx \int_{-\infty}^{\infty}\sigma^2 G_E^{(2)}(\tau)e^{-j\omega\tau}d\tau \\ &= \sigma^2 E_0^4\left\{\left[\cos^4\theta+\sin^4\theta+\sin(2\theta)\cos(\omega_0\tau_0)\mathrm{e}^{-\gamma\tau_0}\right]S_T(\omega)+\right. \\ &\left.\tfrac{1}{2}\sin^2(2\theta)\mathrm{e}^{-2\gamma\tau_0}S_T(\omega)\otimes S_T(\omega)\otimes S_c(\omega)+\cos^2\theta\sin^2\theta\pi\delta(\omega)\right\} \end{aligned} \tag{7}$$

where 2γ is the laser linewidth and the $\otimes$ expresses convolution. The $S_c(\omega)$ is shorted for

$$\begin{aligned} S_c(\omega) &= 4\pi\cos^2(\omega_0\tau_0)\delta(\omega)+\frac{8\gamma}{(2\gamma)^2+\omega^2}\left\{ch(2\gamma\tau_0)\text{-}\cos(\omega\tau_0)+\right. \\ &\left.\cos^2(\omega_0\tau_0)\left[\cos(\omega\tau_0)-e^{-2\gamma\tau_0}-\frac{\sin(\omega\tau_0)2\gamma}{\omega}\right]\right\} \end{aligned} \tag{8}$$

$S_T(\omega)$ is the spectrum of the modulation envelope and the NRZ-OOK signal spectrum can be expressed as

$$S_T(\omega) = \tfrac{1}{2}\pi\delta(\omega) + \tfrac{1}{4}T\,\mathrm{sinc}^2(\tfrac{\omega T}{2\pi}) \tag{9}$$

Omitting sophisticated derivation and assuming phase matching factor[6] $\cos(\omega_0\tau_0)=\frac{1}{2}$ and laser linewidth $2\gamma = 10MHz$, the detected power spectrum as a function of frequency and angle θ are shown in figure 2. For $\theta = 0^\circ$ or 90°, the power of the RF spectrum is the minimal, and for $\theta = 45^\circ$, it is the maximal. The inset of figure 2 shows the theoretical results of the frequency components within 400MHz of the RF spectrum. There is a power difference of the RF spectrum between different launching angles and the power difference is getting exaggerated large at low frequency which is more obvious in the concerned window.

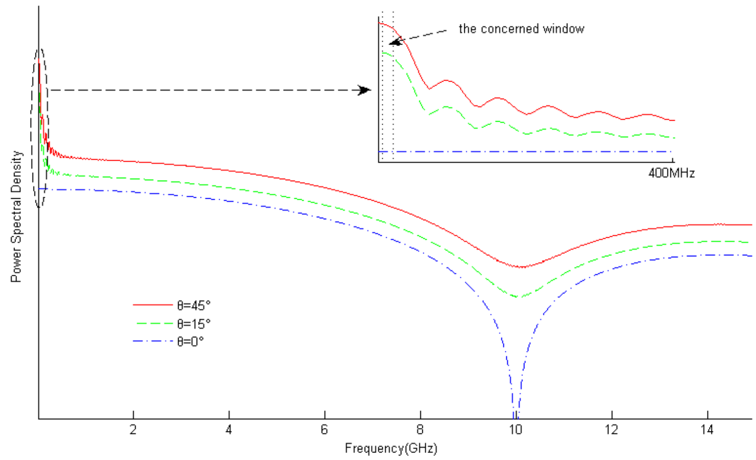

Figure 2. The dependence of power spectrum on frequency and θ

Thus, selecting the particular range of the RF spectrum and detecting the power can be treated as a direct indication of the misalignment between the PDM signals and the PBS. The scheme of polarization division demultiplexing is available by minimizing the RF signal.

3. EXPERIMENT SETUP AND RESULTS

Figure 3 shows the experimental setup for the PDM system. The CW light is modulated with 2^{31}-1 pseudo-random binary sequence (PRBS) 10Gb/s data to generate a 10Gb/s NRZ-OOK signal and split by a 3dB coupler into two branches. A time delay line is set 15ns in one branch to make two channels synchronized. Signals are combined with a polarization beam combiner (PBC) and amplified to by an erbium-doped optical fiber amplifer (EDFA). Transmission is performed in a 100km signal-mode fiber (SMF) and a 20km dispersion compensation fiber (DCF). After transmission, the signal is selected with a 0.2nm optical filter and amplified to about 5dBm, then sent to the demultipelxer.

The architecture of the demultiplexer is shown in figure 3. As a part of the demultiplexer, a commercially available PC, EOSPACE PC-B4-00, with an analog control input port is used. The PC is placed in front of the PBS for controlling the SOPs of the PDM signals. The output optical signal of one PBS port is firstly converted to electrical signal by a 10GHz photo detector (PD), and then the output RF signal is filtered within 9.5MHz to 11.5MHz and amplified, and detected with a low frequency RF power detector to generate the control signal. The control signal is converted to digital signal and sent to digital signal processor (DSP) which controls the PC with the feed-back control algorithm.

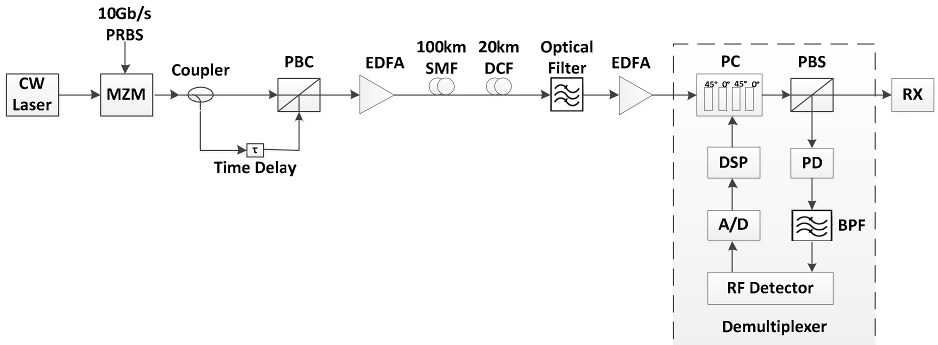

Figure 3. The experimental setup for the PDM system

The RF spectrum of the photocurrent is shown in figure 4, in the cases of two critical launching angles between the PDM signals and the PBS. Within the certain bandwidth, the RF power level is maximal when $\theta = 45^\circ$ or minimal when $\theta = 0^\circ$ or 90° , and the power difference for this two cases is about 10dB.

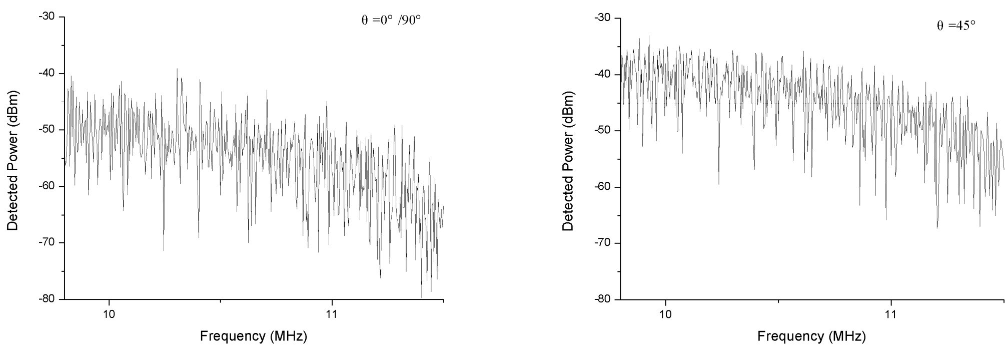

Figure 4. The RF spectrum of the photocurrent

Figure 5 shows the eye diagrams of the output optical signal at the PBS port. The eye diagram is clear and opened completely when $\theta = 0^\circ$ or 90° and the eye diagram is close when $\theta = 45^\circ$.

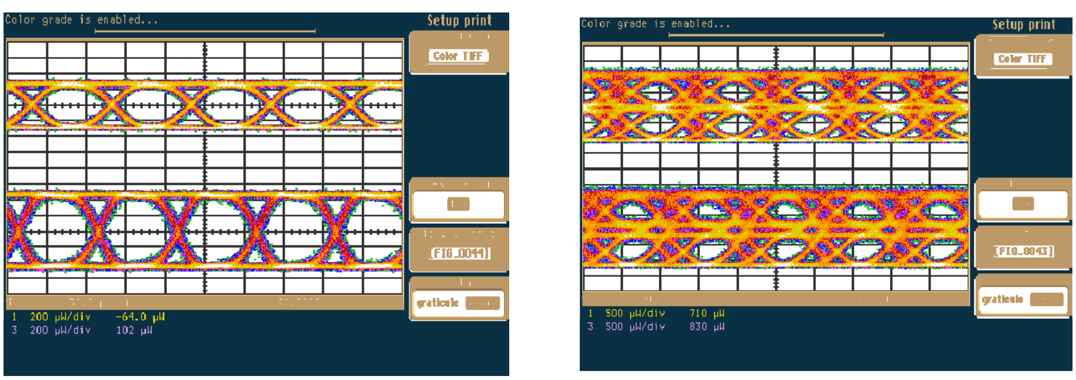

Figure 5. The eye diagrams of the output optical signal

4. CONCLUSION

In this letter, we have proposed a novel automatic optical polarization demultiplexing method used the low frequency RF power as control signals for PDM system. The RF detection window is about 9.5MHz~ 11.5MHz with power difference 10dB. Those power differences detected at different angle between PC and PBS can be used as automatic control signals.

The detailed analysis of the experimental results and the performance of the automatic polarization demultiplexing method will be investigated in the near future.

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REFERENCES

[1] J. C. Rasmussen, Automatic PMD and chromatic dispersion compensation in high capacity transmission, LEOS Summer Topical Meetings (2003), p. 47–48

[2] S. Bhandare, D. Sandel and R. Noé, 5.94 Tbit/s, 1.49bit/s/Hz (40×2×2×40 Gbit/s) RZ-DQPSK Polarization Division Multiplex C-Band Transmission over 324 km, IEEE Photon. Technol. Lett., Vol. 17(2005), p. 914-916.

[3] P. Martelli, P Boffi, M. Ferrario, L. Marazzi, P. Parolari, S. M. Pietralunga, A. Righetti, R. Siano, M. Torregiani, and M. Martinelli, Endless Polarization Stabilizer for High Bit-rate Polarization-Division Multiplexed Optical Systems, in Proc. OFC'2008, San Diego, CA, USA, 2008, paper JWA66.

[4] M. I. Hayee, M. C. Cardakli, A. B. Sahin, and A. E. Willner, Doubling of bandwidth utilization using two orthogonal polarizations and power unbalancing in a polarization-division-multiplexing scheme, IEEE Photon. Technol. Lett. 13 (2001), p. 881-883.

[5] P. Gallion and F. J. Mendieta and R. Leconte, Single-frequency laser phase-noise limitation in single-mode optical fiber coherent detection systems with correlated fields, J. Opt. SOC. Am. , vol.72 (1982), p. 1167-1170.

[6] F. B. Gallion and G. DeBarge, Quantum phase noise and field correlation in single frequency semiconductor laser systems, IEEE J. Quantum Electron., Vol. QE-20 (1984), p. 343-349.

[7] Mercer, L.B., 1/f frequency noise effects on self-heterodyne linewidth measurements, J. Lightwave Technol. Vol. 9(1991), p. 485 - 493.

[8] Zinan Wang and Chongjin Xie, Automatic optical polarization demultiplexing for polarization division multiplexed signals, J. Optics Express. Vol. 17(2009), p. 3183-3189.