Fading Mitigation in Homodyne RZ-QPSK via Delay-Diversity Transmission

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Abstract: Turbulence-induced fading in free-space transmission of optical RZ-QPSK can be mitigated in homodyne detection via delay-diversity. A SNR gain of 2.6 dB is obtained using orthogonal polarizations with delay comparable to the turbulence correlation time.

OCIS codes: (060.1660) Coherent communications; (060.2605) Free-space optical communication

1. Introduction

Delay-diversity in direct detection of optical OOK in two orthogonal polarizations has been shown to be an effective approach to combat fading [1]. It employs transmission of two orthogonal polarizations, V and H, carrying the same information but with a relative delay T_d comparable to the turbulence correlation time (τ_c). At the receiver, the V and H data are detected separately, resynchronized, and combined. Since $T_d \geq \tau_c$, fading suffered by V and H are approximately independent and the average bit-error-rate (BER) of the polarization-combined signal (VH) is approximately the BER product of the V and H channels: $BER_{vh} \approx (BER_v)(BER_h)$. The SNR is effectively improved. This has been shown previously for direct detection of optical OOK signals [1]. The effectiveness of this technique for homodyne detection of optical QPSK signals, however, has not been reported to our knowledge. In this paper, we describe a fading mitigation experiment for homodyne detection of optical RZ-QPSK using delay-diversity transmission of V and H polarizations. The homodyne detected RZ-QPSK in the two polarizations was captured and stored for off-line processing. BER were computed from the processed complex IQ data. Our results showed that BER of the VH signal improved significantly when $T_d \geq \tau_c$. A SNR gain of 2.6 dB at BER ~ 2×10^{-3} was obtained.

2. Fading mitigation experiment

From the transmitter, optical RZ-QPSK signal at 80 MSym/s in two polarizations was launched into a turbulent air path via a fiber-optic circulator followed by a fiber collimator (Fig. 1) with a beam diameter ~ 15 mm. A retro-reflector placed about 3.6 m from the fiber collimator directs the optical beam back into the fiber collimator and to the receiver via the circulator. A convective turbulence generator (hotplate and/or space heater) was placed approximately halfway between the collimator and the retro-reflector. The turbulence generator can produce τ_c of ~ 5, 10, and 30 ms with a scintillation index ~ 0.1 to 0.15. At the transmitter, a 1550-nm narrow-linewidth Tx laser connected to two $LiNbO_3$ optical quadrature modulators (QM) produces two optical QPSK signals. These signals are combined, using a polarization beam combiner followed by an optical amplifier, before launching into the turbulent channel. A digital electronic FPGA Tx board provides four 80 Mb/s bipolar RZ electrical signals for two polarizations: I_V, Q_V, I_H, and Q_H that drive the two RF inputs of each of the two QMs. Pseudo-random bit sequence with word length of 2^{23}-1 and 2^7-1 was used for the I and Q channel for both polarizations. The I_V and Q_V signals from the Tx board can be delayed from the I_H and Q_H signals by up to 13 ms. At the receiver (Fig. 1), the two polarizations were first separated using a polarization controller (PC) and a polarization beam splitter (PBS). This is followed by a pair of $LiNbO_3$ optical 90° hybrids [2] that combine the QPSK signals with the local laser (LO) before balanced detection. The frequency mismatch between the LO and the Tx laser was controlled to within 1% of the symbol rate. The homodyne detected optical RZ-QPSK in two orthogonal polarizations produces four electrical signals: IV, QV, IH, and QH at the outputs of the four sets of balanced detectors. These four signals were simultaneously captured by a pair of high-speed dual-channel digitizers sampling at 80 MS/s synchronized with the clock of the Tx board. The captured data were stored in a desktop computer for off-line processing using Matlab.

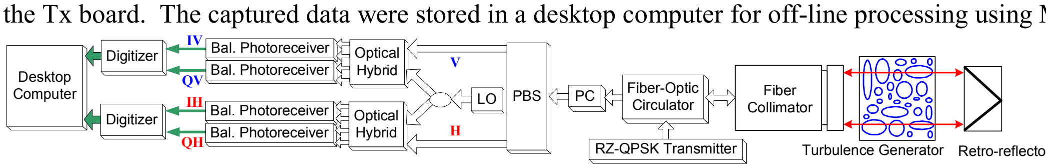

Fig. 1. Fading mitigation and homodyne receiver setup for the optical RZ-QPSK two-pol. delay-diversity transmission.

3. Test results

Typical results of the captured raw and processed complex IQ data for V and H are shown in Fig. 2 for τ_c ~ 10 ms and T_d ~ 13 ms. The 'donut' shape of the raw IQ data on the left is a result of laser frequency mismatch. After applying the phase rotation compensation algorithm, the QPSK constellation for both V and H can be clearly seen on the right of Fig. 2. The VH constellation (green) was obtained by combining the resynchronized V and H data. It can be readily seen that the VH signal has a better SNR than either V or H signal.

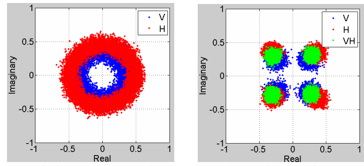

Fig. 2. IQ plots of real and imaginary part of the captured QPSK signal. Left: raw unprocessed V (blue) and H (red) data. Right: after phase rotation compensation, resynchronization, and recombination of the V and H polarization.

The BER for V and H as well as for the VH data was computed for ~ 19M sample points. Fig. 3 shows BER results for V (BER_v), H (BER_h), and VH (BER_{vh}) for τ_c ~ 10 ms and T_d of 0, 6.6, and 13 ms. The product (BER_v)(BER_h) is also shown. For T_d equals to zero (no delay) or less than τ_c no significant BER improvement for VH is expected which is consistent with the test results. Table 1 summarizes BER for different T_d and τ_c. For T_d = 13 ms and τ_c ~ 10 ms, significant BER improvement of the VH signal was observed with $BER_{vh}=5.64\times10^{-5}$ and $(BER_v)(BER_h)=5.67\times10^{-5}$ giving, $BER_{vh}\approx(BER_v)(BER_h)$ for $T_d \geq \tau_c$ as can be seen in Table 1. From these results, it is evident that delay-diversity is effective in mitigating turbulence-induced fading for transmission and homodyne detection of optical RZ-QPSK signals. From the BER shown in Table 1, the theoretical SNR can be computed. The SNR gain due to the VH signal relative to the V or H polarizations can therefore be deduced. For the case of T_d = 13 ms and τ_c ~ 10 ms, SNR gain (V relative to VH) of 2.6 dB at BER ~ 2×10^{-3} was obtained.

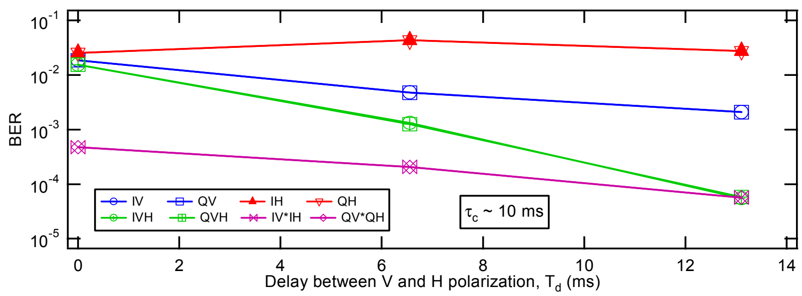

Fig. 3. BER versus T_d for τ_c ~ 10 ms. IV (IH) and QV (QH) in blue (red) denote BER for I and Q of vertical (horizontal) polarization. IVH and QVH in green denote BER for I and Q of polarization-combined signals. The product of BER of V and H in purple for the I (Q) channel is represented by IV*IH (QV*QH).

Cases	T_d (ms)	τ_c (ms)	BER_v (I/Q)	BER_h (I/Q)	(BER_v)(BER_h) (I/Q)	BER_{vh} (I/Q)	SNR_v gain I/Q (dB)
Hotplate	0	~ 30	0.00018895 / 0.00018511	0.00051926 / 0.0005109	9.8114e-008 / 9.4569e-008	5.2684e-005 / 4.6053e-005	0.75496 / 0.81453
Hotplate	6.55	~ 30	2.8947e-006 / 3.7895e-006	0.00063774 / 0.000771	1.8461e-009 / 2.9217e-009	1.5789e-007 / 3.6842e-007	1.0453 / 0.8753
Hotplate	13.1	~ 30	0.00013983/0.00014168	0.021829/0.021938	3.0523e-006/3.1082e-006	2.9127e-005/3.2293e-005	0.87766 / 0.83292
Space heater + hotplate	0	~ 10	0.018634 / 0.018672	0.025598 / 0.025568	0.000477 / 0.00047739	0.015523 / 0.015428	0.30191 / 0.3152
Space heater + hotplate	6.55	~ 10	0.0047766 / 0.0047362	0.04331 / 0.04329	0.00020688 / 0.00020503	0.0013214 / 0.0012538	1.2899 / 1.3259
Space heater + hotplate	13.1	~ 10	0.0020772 / 0.0020791	0.027416 / 0.02739	5.6949e-005 / 5.6947e-005	5.4983e-005 / 5.7727e-005	2.6025 / 2.5766
Space heater	0	~ 5	0.0052712 / 0.0052667	0.01864 / 0.01862	9.8255e-005 / 9.8067e-005	0.0057589 / 0.0057021	(-0.10569 / -0.094739)
Space heater	6.55	~ 5	0.001355 / 0.0013452	0.040529 / 0.040621	5.4917e-005 / 5.4641e-005	2.6368e-005 / 2.5684e-005	2.5953 / 2.6021
Space heater	13.1	~ 5	0.00012031 / 0.00012469	0.02842 / 0.02847	3.4192e-006 / 3.5498e-006	0 / 0 (no error count)	No error count

Table 1. Summary of BER computed from the processed I/Q data for different T_d and τ_c. SNR gain for V relative to VH (SNR_v) calculated from the BER are also shown. Note that zero BER means no error has occurred for up to 19M samples.

In summary, turbulence-induced fading can be effectively mitigated using delay-diversity with orthogonal polarizations in homodyne detection of free-space transmission of optical RZ-QPSK at 80 MSym/s. Test results have verified that when $T_d \geq \tau_c$, $BER_{vh} \approx (BER_v)(BER_h)$. For the case of T_d = 13 ms and τ_c ~ 10 ms, a SNR gain of 2.6 dB at BER ~ 2×10^{-3} was obtained. The SNR gain provides additional link margin that can be used, e.g., for longer transmission distance.

References

[1] S. Trisno, *et al.*, "Delayed diversity for fade resistance in optical wireless communications through turbulent media," Proc. SPIE 5596, 385-393, 2005.

[2] P. S. Cho, *et al.*, "Integrated optical coherent balanced receiver," Proc. of Coherent Optical Technology and Application, Whistler, Canada, 28-30 June 2006, paper CThB2.