Polarization Multiplexed 2×20Gbit/s RZ Transmission using Interference Detection

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Abstract: Polarization division multiplex doubles optical fiber capacity. Interchannel interference is detected in the RX and employed as a control signal for polarization tracking. Transmission over 33km of DSF with a 6.25ps PMD tolerance is demonstrated.

OCIS codes: (060.2330) Fiber Optics Communications, (060.4080) Modulation, (060.4230) Multiplexing

1. Introduction

For capacity doubling of existing trunk lines with given optical bandwidth, polarization division multiplex (PolDM) [1-5] is advantageous due to its superior sensitivity, acceptable polarization mode dispersion (PMD) tolerance and terminal equipment simplicity. Previously we have employed correlation schemes to derive error signals for endless polarization control [4]. However, these react only when interchannel interference is already fairly large. Here this interference is cultivated, detected and minimized for improved polarization matching.

2. Principle:

In a PolDM receiver one photocurrent can be written as

$$i \propto b_1 \cos^2 \psi/2 + b_2 \sin^2 \psi/2 + 2 b_1 b_2 \cos\varphi \sin\psi$$

where φ is a phase difference between the orthogonally polarized signals carrying information bits b_1, $b_2 \in \{0,1\}$ at the transmitter, and ψ is a retardation angle representing subsequent mode conversion. Perfect alignment requires $\psi = 0$. Electrical correlation of i with the regenerated information bit b_2 at the other decision circuit output results in an error signal which indicates how well information bit b_1 can be regenerated [4]. It is proportional to $\sin^2 \psi/2$ if angle φ is modulated so that $\overline{\cos\varphi} = 0$ holds, where the overbar means averaging.

The term $2 b_1 b_2 \cos\varphi \sin\psi$ indicates interchannel interference proportional to $\sin\psi$, which is much larger than $\sin^2 \psi/2$ for $|\psi| << 1$. If φ is modulated linearly by a serrodyne phase modulator or a frequency shifter, a sinusoid results which can be detected. Alternatively, sinusoidal modulation of φ results in a Bessel spectrum in the photocurrent. Even and odd Bessel amplitudes lines are $J_{even} \propto \cos\overline{\varphi} \sin\psi$ and $J_{odd} \propto \sin\overline{\varphi} \sin\psi$, respectively. The mean interchannel phase difference $\overline{\varphi}$ can not be controlled usually. However, a control signal proportional to $\sin^2 \psi$ but independent of $\overline{\varphi}$ is obtained if the powers of at least one even and one odd Bessel line are measured and combined with suitable weighting. This signal contains less noise than a correlation signal. Its square root can be taken to obtain a control signal proportional to $|\sin\psi|$, if this is desired.

3. Transmission experiment

An optical 20Gbit/s RZ signal was generated, using a 40Gbit/s multiplexer (Siemens) with every other input bit being zero and a $LiNbO_3$ modulator [6]. The signal from transmitter TX was split 1:1 and recombined in a polarization beamsplitter (PBS) with orthogonal polarizations, after delaying one branch signal by $\tau = 5.6\text{ns}$ (Fig. 1 left). The mean phase difference $\overline{\varphi}$ fluctuated with laser frequency and temperature. This 2×20Gbit/s PolDM signal was transmitted through EDFAs, 33 km of dispersion-shifted fiber, an attenuator and a bandpass filter. For simplicity only one channel was recovered at the receiver side. A commercial electrooptic polarization transformer

(EPT) was followed by a fiberoptic polarizer (POL), a 20GHz photoreceiver and a 40Gbit/s demultiplexer/regenerator, every other output bit of which was discarded.

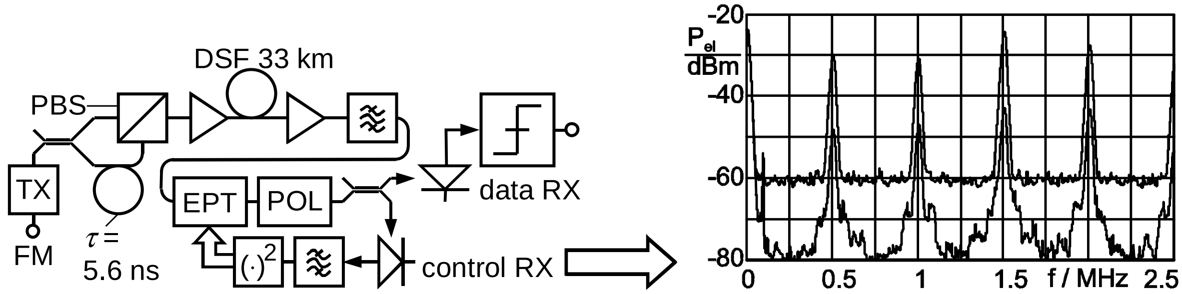

Fig. 1: 2×20Gbit/s PolDM transmission setup (left), and electrical Bessel spectra in control receiver (right) with polarization control switched off: maximum (top curve) and minimum (bottom curve) interference with polarization control on

A portion of the received signal was tapped off into a slow photoreceiver for control purposes. Normally one would tap the detected electrical data signal instead. A sinusoidal frequency modulation at $F = 500\text{kHz}$ was applied to the TX laser, leading to a peak-to-peak optical frequency deviation of $\Delta f_{pp} = 240\text{MHz}$. This resulted in a differential phase modulation index $\eta = \pi \Delta f_{pp} \tau \operatorname{sinc}(\pi F \tau) = 4.2$. Bessel line J_0 is corrupted by DC anyway, and J_1 can be corrupted by FM distortions or parasitic laser amplitude modulation, especially for larger Δf_{pp} which are needed for lower τ. Therefore the powers P_2, P_3, P_4 of J_2, J_3, J_4 were detected. Due to suitable weighting, $0.64P_2 + P_3 + 1.32P_4$, the control signal was not only independent of $\overline{\varphi}$ but also, to first order, of changes of η. This is useful if laser FM efficiency drifts due to reflections or ageing.

4. Results

The DFB laser linewidth Δf_l was broad (~25 MHz), oscillatory and non-Lorentzian but much of the power was contained in a main lobe having 5 MHz width. The normalized power in each Bessel line is $e^{-2\pi \Delta f_l \tau}$ and therefore suffers a 3 dB penalty for $\Delta f_l \tau = 0.11$. The value $\tau = 5.6\text{ns}$ turned out to be sufficiently small. Fig. 1 (right) shows Bessel spectra in the control receiver. Maximum hold mode was taken because even and odd Bessel lines faded in antiphase. The levels measured at $F = 500\text{kHz}$ are higher than the corresponding true J_1 amplitudes, mainly due to FM distortion. The electrical interference signal can be suppressed by ~20 dB by suitable polarization setting which indicates that the residual polarization mismatch error at the operation point is $|\psi| \sim 0.1$. Either channel could be acquired, depending on polarization setting before control was switched on.

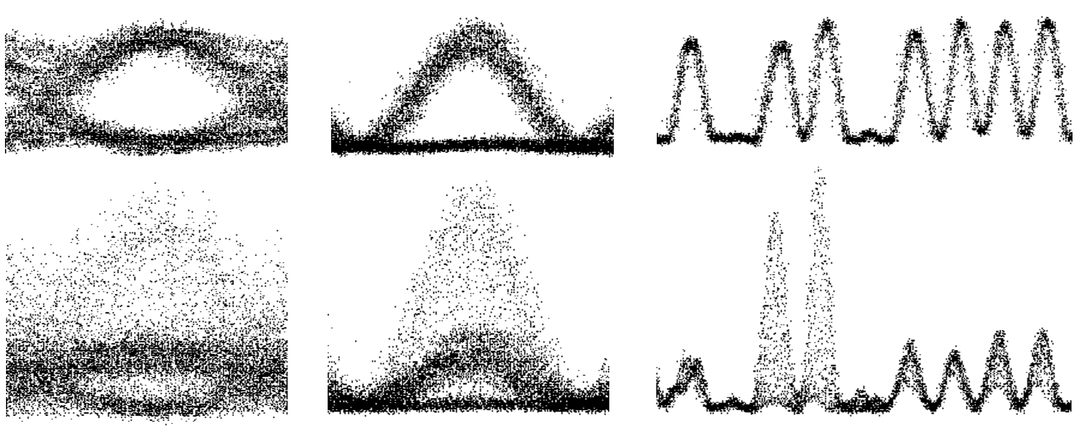

Fig. 2: 20Gbit/s eye diagrams in data RX (left), and eye diagrams (middle) and data patterns (right) in 50GHz monitor receiver, with (top) and without (bottom) polarization control in a worst case.

Fig. 2 shows eye diagrams in an additional 50GHz monitor receiver (top), and data patterns in the data RX (bottom). Interference which occurs for $b_1 = b_2 = 1$ is well suppressed by polarization control. BER was measured on one demultiplexed 2.5 Gbit/s data stream. For 33 km DSF, a Q factor of 12.2 was obtained by scanning the decision threshold (Fig. 3). Pieces of polarization-maintaining fiber were then inserted with worst-case orientation in order to assess PMD tolerance. The Q factor dropped to 9.1 in the presence of 6.25 ps of differential group delay, which may be considered as acceptable. Even for 9 ps it was as high as 6.7.

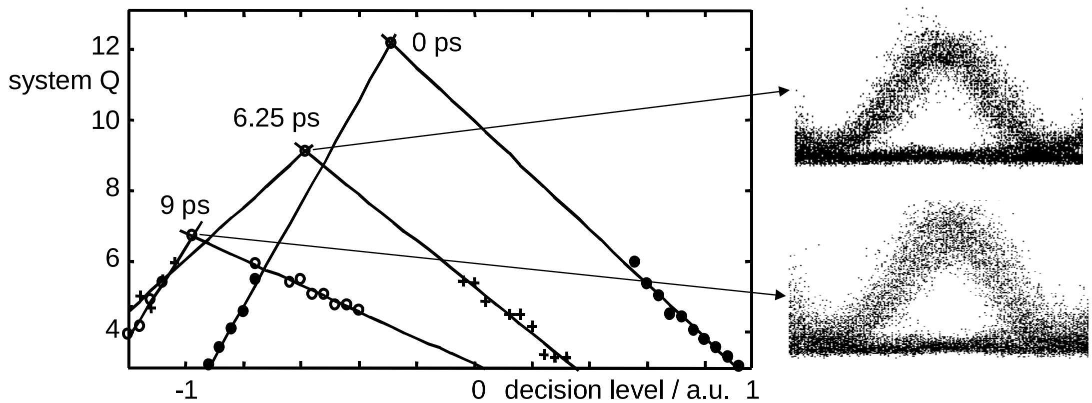

Fig. 3: Q factor measurement with 33 km of DSF and 0, 6.25 or 9 ps of differential group delay

5. Discussion

This experiment shows a net superiority of the interference detection scheme over the previously employed correlation scheme [4] for polarization alignment in a PolDM receiver. It is also simpler to implement.

The same experimental complexity as here was employed in [5] where a polarization controller improved the separation of adjacent, densely packed WDM channels with orthogonal polarizations. The permissible DGD×bitrate product was 0.06. The present scheme needs just half as many lasers in a WDM environment and supports a DGD×bitrate product of ~0.125.

6. Conclusions

2×20Gbit/s RZ PolDM transmission has been demonstrated over 33 km of DSF. Interchannel interference was tailored by differential phase modulation at the transmitter. Detection of the resulting Bessel spectrum in the receiver allowed to adjust the polarization transformer for minimized interference. The permissible DGD×bitrate product was ~0.125.

7. References

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