BER Measurements of a 40Gb/s Receiver with Adaptive Threshold using Polarization Scrambling

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Abstract:

Polarization scrambling is proposed to quantify the penalties of polarization dependent effects in optical receivers. The results will be dependent on the relative speed of the polarization changes and the control circuits in the receiver.

Introduction:

Over recent years the design of receivers for high bitrate optical transmission signals has evolved from fixed threshold receivers with a decision threshold level kept at a fixed ratio to mean optical power, towards adaptive threshold receivers, which optimize the bit error ratio (BER) under all signal conditions. Usually forward error correction (FEC) algorithms are applied to improve resistance against noise from amplified spontaneous emission. Optimization of the decision threshold becomes mandatory in order to achieve best performance for all types of signal degradation, like residual chromatic dispersion and polarization mode dispersion (PMD) [1]. During system design the worst case penalties associated with these signal distortions are of interest for allocation of system margins. For short measurements fast polarization scrambling is preferred in order to provide sufficient statistical coverage of the entire Poincare sphere [2]. Since in particular PMD is known to be a time varying effect, adaptation rate of the receiver becomes a critical parameter. Control loops, which use BER estimation from corrected errors out of FEC decoders [3], exhibit limited bandwidth from integration time constants and signal processing delay. This ‘dead-time’ limits the control speed. When testing a transmission system with BER-based controls under normal conditions care must be taken that a) enough bit errors are present in order to achieve full dynamics of the control, and b) temporal variations of the signal are not faster than the limit of the control circuit. However, when employing the measurement technique of [2], which deliberately scrambles the polarization at speeds so high the controls cannot follow, it will adapt to a mean value which will be shown below. Intention of this paper is to give some guidance on the interpretation of the results obtained by the penalty characterization using slow as well as fast polarization scrambling.

Experimental setup:

The influence of scrambling and the control loops on the BER is tested with a setup as shown in Figure 1a). PRBS $2^{31}-1$ data is encoded using FEC and sent with a line rate of 43Gbit/s. The polarization is either scrambled continuously or changed manually to find the worst case coupling condition for the following 1st order PMD-Emulator set to 12.5ps of DGD. As polarization controller, we use the commercially available Agilent 11896A that offers 8 different scrambling speeds (Scan Rates). In order to generate a non-zero BER even for optimum receiver setting, the OSNR can be adjusted by an attenuator-amplifier-stage. The receiver following the optical filter removes the FEC-overhead and is so able to calculate the BER.

Relating the BER to the speed of a Polarization Scrambler requires a measure for this speed which is derived from a polarimeter that is able to monitor the Stokes parameters. These parameters represent the power in certain states of polarization and are thus predestined for analyzing polarization dependent effects. The Stokes parameters are translated into frequency domain by discrete Fourier transform and averaged to one spectrum. To suppress the effect of high-frequency polarization changes with low amplitude that we had noticed, the analyzed bandwidth is limited to 40Hz. We define the equivalent scrambler bandwidth (ESB) as the frequency that confines the band incorporating 95% of the spectrum. Figure 1b) shows the spectra for a Scan Rate of 1, 5 and 8, the corresponding ESB are found to be 0.39, 9.0 and 15.6Hz, respectively.

Results:

In Figure 2a) the dependence of the BER on the different scrambler speeds can be seen. The measurements were performed with regular speed of the threshold control loop (dash-dotted) and with the control loop slowed down by a factor of 10 (solid). Figure 2b) shows the measured distribution of the threshold values for the slow control loop.

Distortions due to PMD affect the optimum threshold setting. For slow scrambling, the threshold control is able to set the threshold correctly resulting in a low BER. Note that these measurements require a measurement period of several hours as all states of polarization have to be covered. For large scrambling frequencies the threshold con-
verges to a constant value. It results in a BER close to the BER we get for a fixed worst-case polarization with the threshold optimized to this fixed polarization. Optimizing the thresholds manually for both cases yields results close to each other, see Figure 2b), confirming results in [2]. We noted that at an ESB around 3Hz, the BER shows fluctuations leading to an increased variance of the measured BER. At these scrambling speeds the control loop shows a resonance effect because the signal’s fluctuations are too fast for the control loops to follow but too slow for the control loops to settle at a fix value. Measuring at these Scrambler speeds may easily lead to invalid results as the increased variance entails an increased measurement period, see dashed add-on to the solid curve in Figure 2a).

Figure 1a) Experimental Setup and b) Scrambler Spectrum

Figure 2a) BER over scrambling frequency (DGD = 12.5ps) and b) Distribution of Receiver Thresholds

Summary:
Receiver characteristics have been investigated in the presence of polarization dependent distortions. Polarization scrambling at different speeds will cause different results for BER (or penalty), when the decision threshold is set dynamically. Low scrambler speeds enable the control loops to follow leading to low BER. Large Scrambler speeds lead to a stable BER close to worst-case BER. Medium speeds however can generate even larger BER as control loops can show resonance effects.

References: