Lehigh University
Center for Optical Technologies

Project Title: ***PMD Equalization and Coding***

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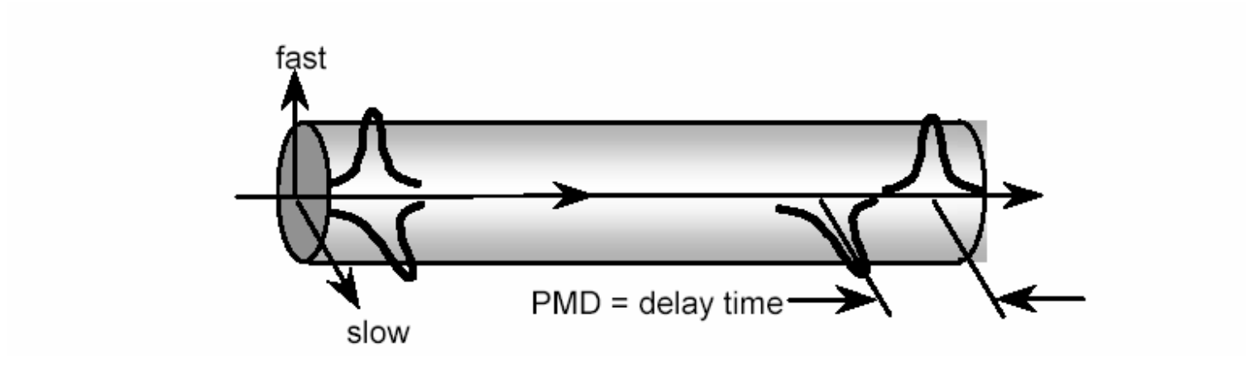
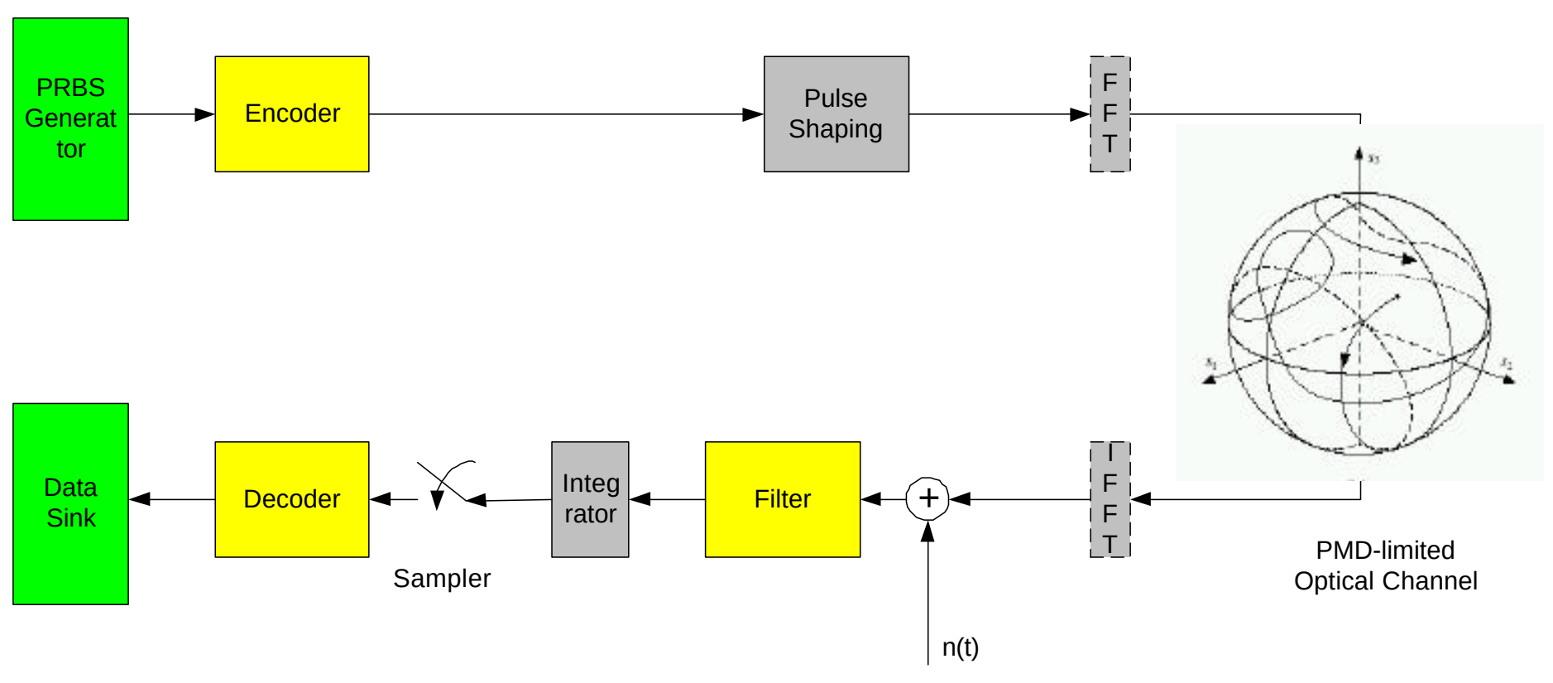
Project Status/Key Milestones/Results: Demonstrated the potential of combined coding and equalization for PMD-limited channels

Polarization mode-dispersion (PMD)

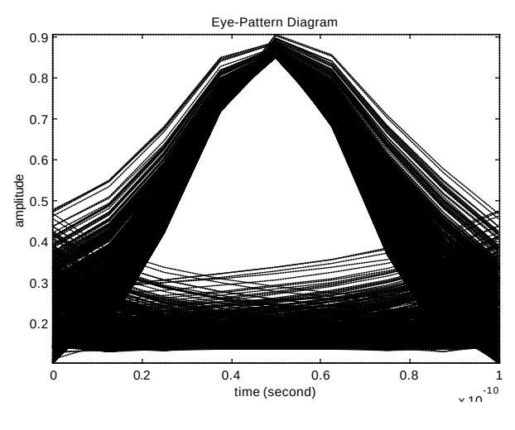
PMD arises in fibers when the cylindrical symmetry is broken due to noncircular core or noncircular symmetric stress [1]. The loss of circular symmetry destroys the degeneracy of the two eigen polarization modes in the fiber, which will cause different group velocities for these modes and thereafter the pulse distortion and system performance degradations.



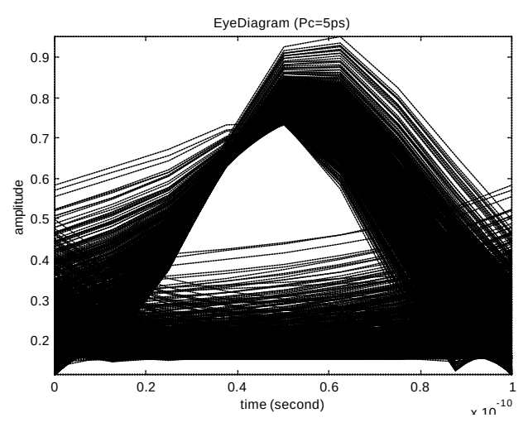
Optical Transmission System with PMD-limited Channel



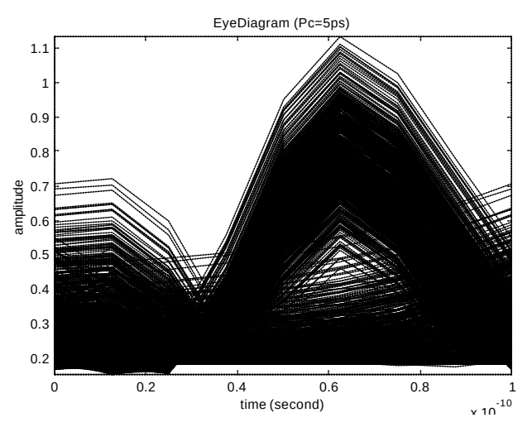
Impact of Intrinsic PMD Pc: unit length DGD



Eye diagram with unit intrinsic PMD of Pc= 3 $\text{ps/km}^{1/2}$

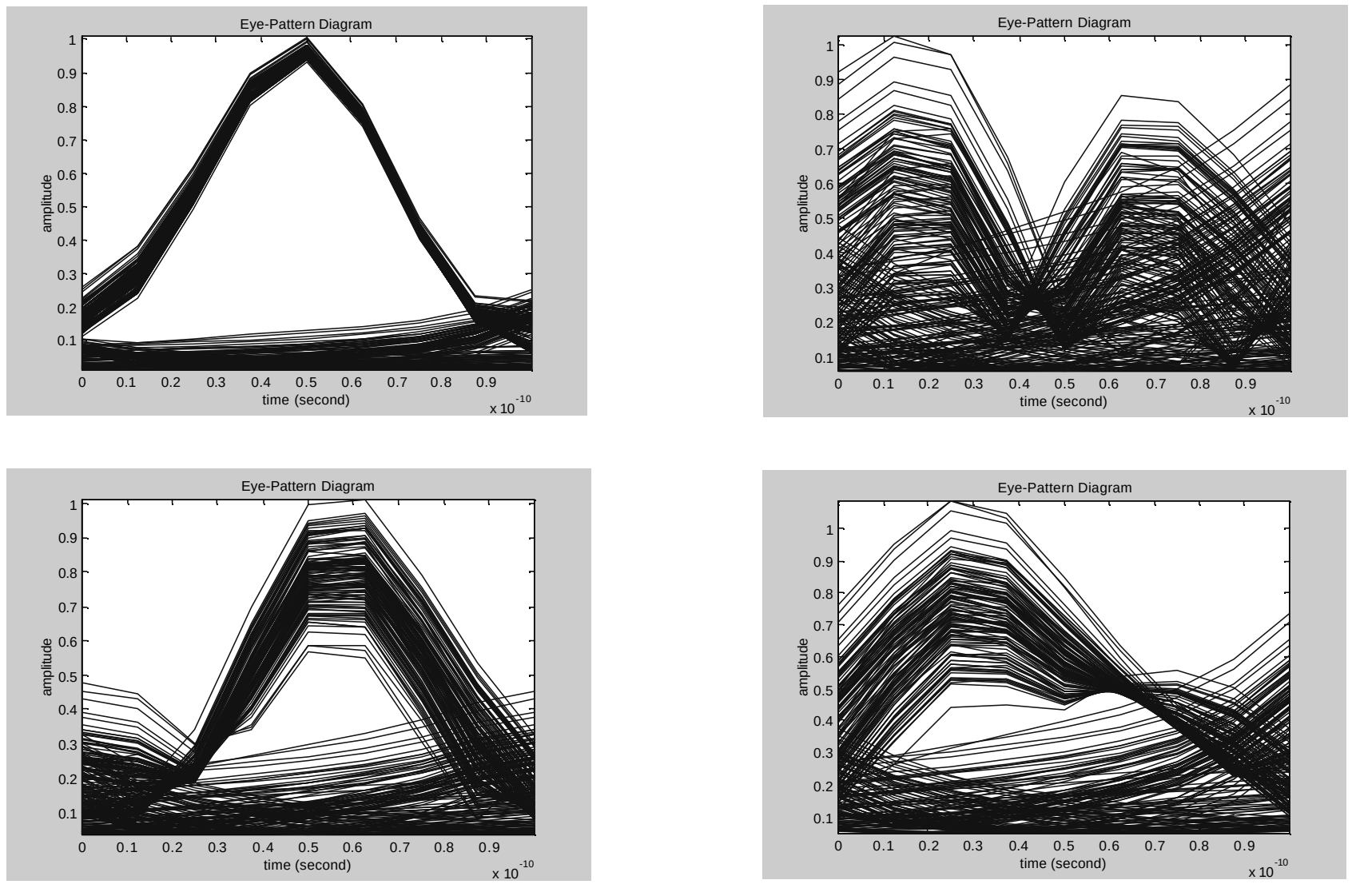


Eye diagram with unit intrinsic PMD of Pc= 3.5 $\text{ps/km}^{1/2}$

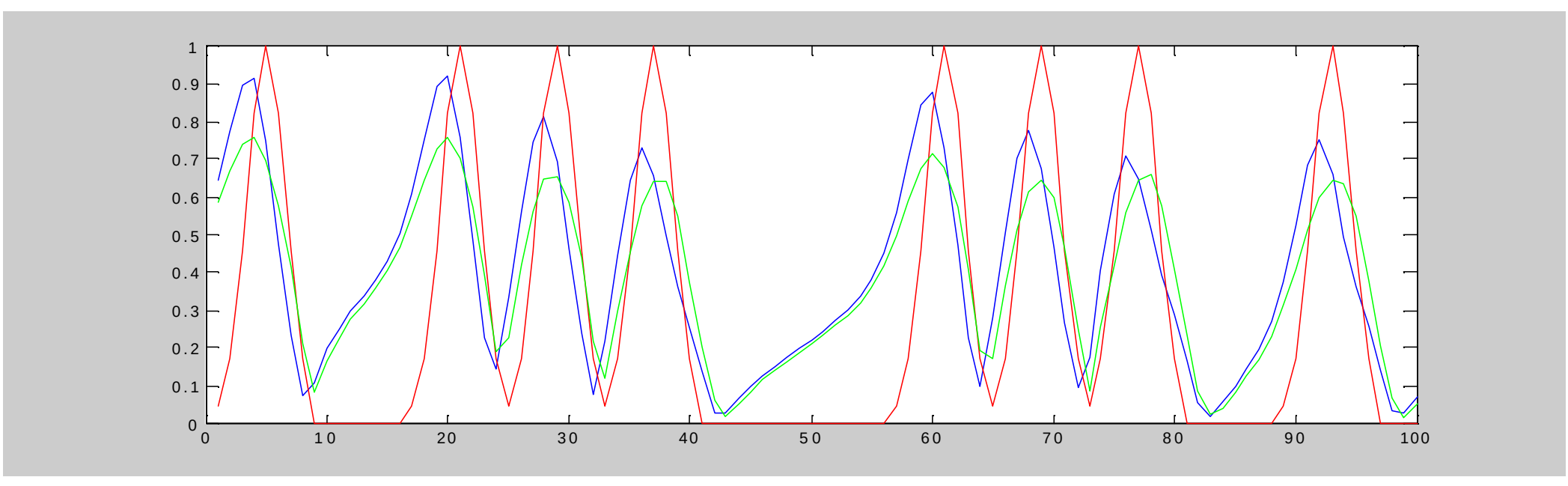


Eye diagram with unit intrinsic PMD of Pc= 5 $\text{ps/km}^{1/2}$

Impact of random mode coupling with same intrinsic PMD



First Order PMD



The offset between the fast mode waveform (green) and the slow mode waveform (blue) is the first order DGD.

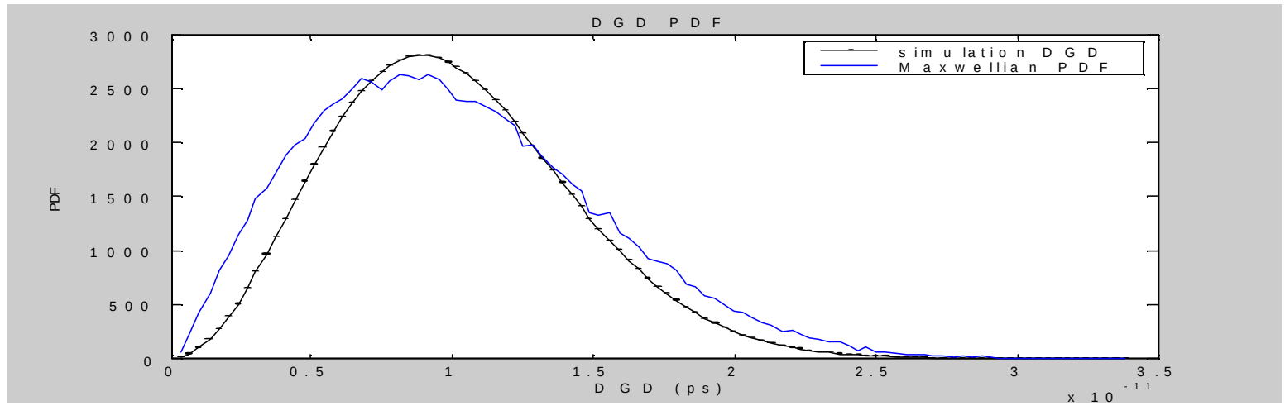
PMD Channel Model

Based on the PMD concatenation rule [2], the model of PMD used in the system simulations is a concatenation of linear birefringence elements oriented at random angles that are chosen randomly over 0 to p . Simulation is performed in Jones space. In the simulation, each section becomes a linear retard matrix sandwiched between two rotation matrices. The rotation matrices, which effectively orient the retarder at a random angle.

$$T(w)=U(a_N)\begin{bmatrix} e^{-jt_N w/2} & 0 \\ 0 & e^{jt_N w/2} \end{bmatrix} U(a_{N-1})\begin{bmatrix} e^{-jt_{N-1} w/2} & 0 \\ 0 & e^{jt_{N-1} w/2} \end{bmatrix} U(a_{N-2})..U(a_1)\begin{bmatrix} e^{-jt_1 w/2} & 0 \\ 0 & e^{jt_1 w/2} \end{bmatrix} U(a_0)$$

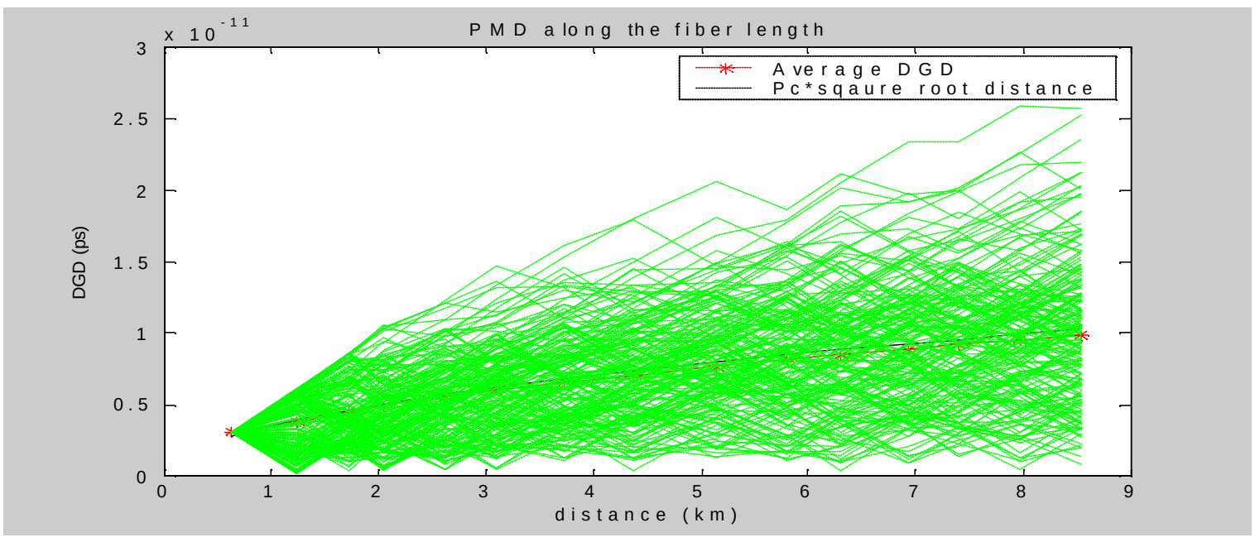
Simulation Results

1. DGD Maxwellian Distribution



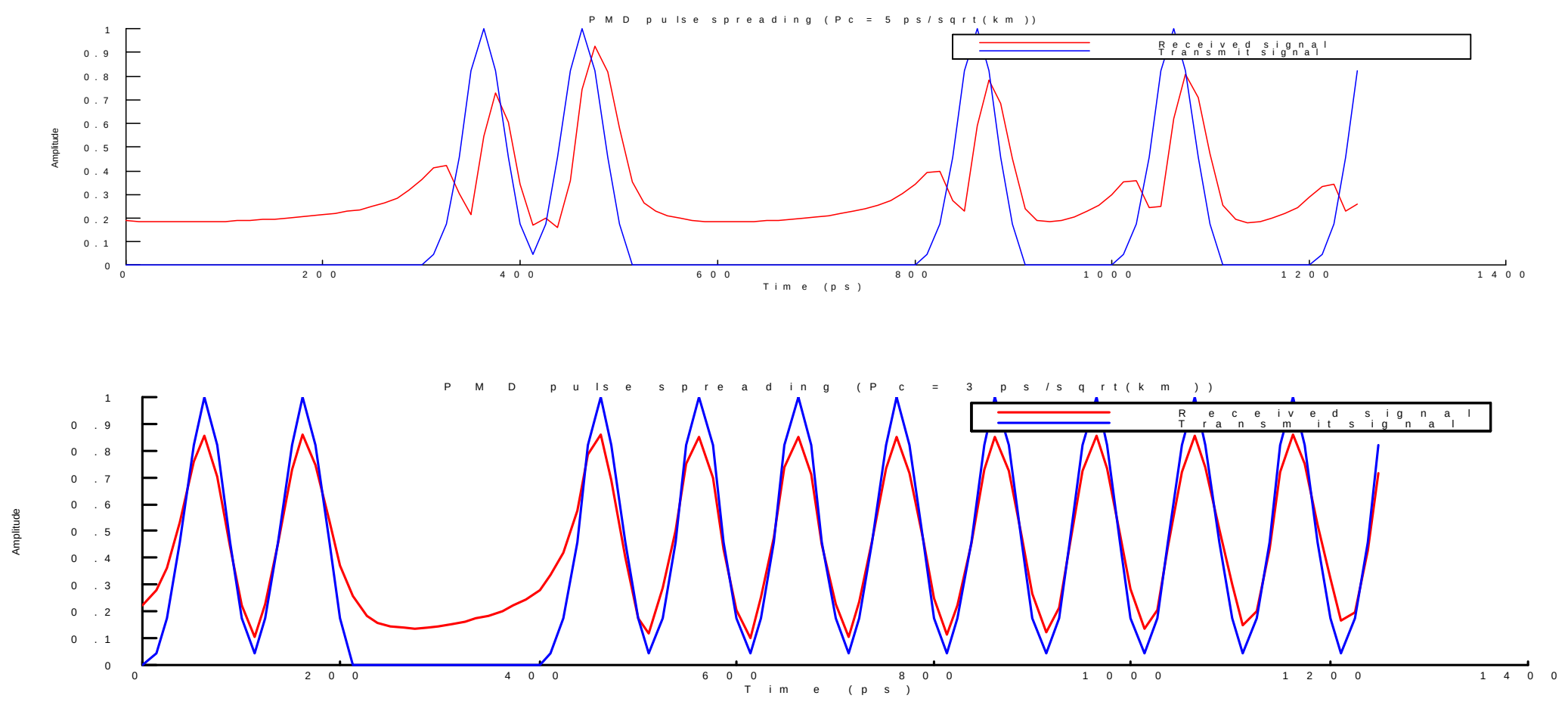
DGD pdf

2. Mean DGD increases with the square root of distance.



Mean DGD vs. distance

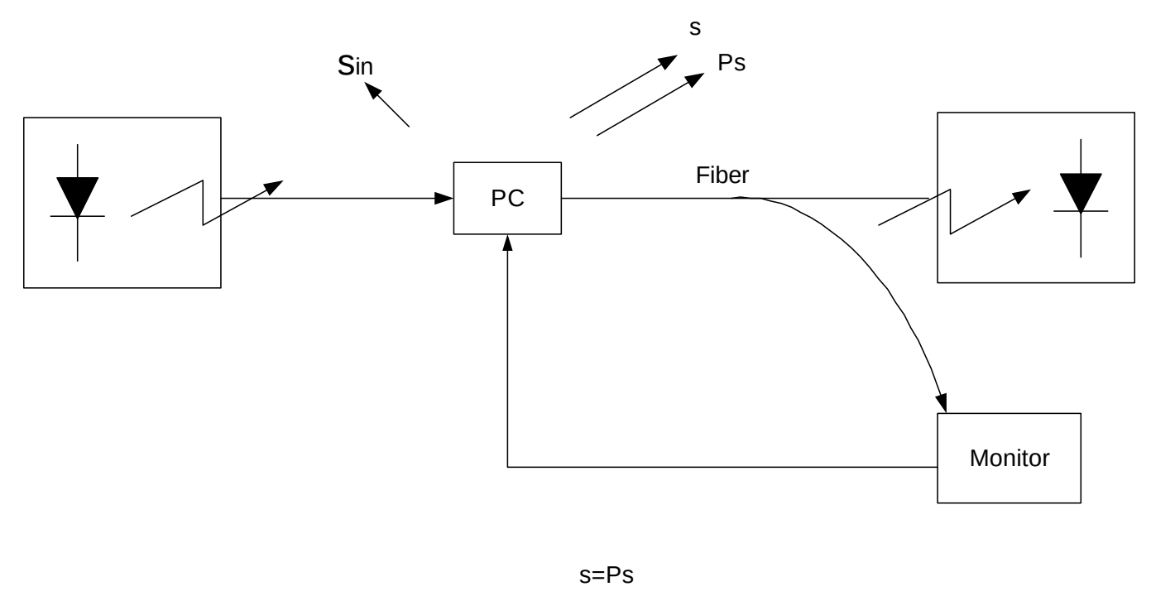
PMD Induced Pulse Broadening



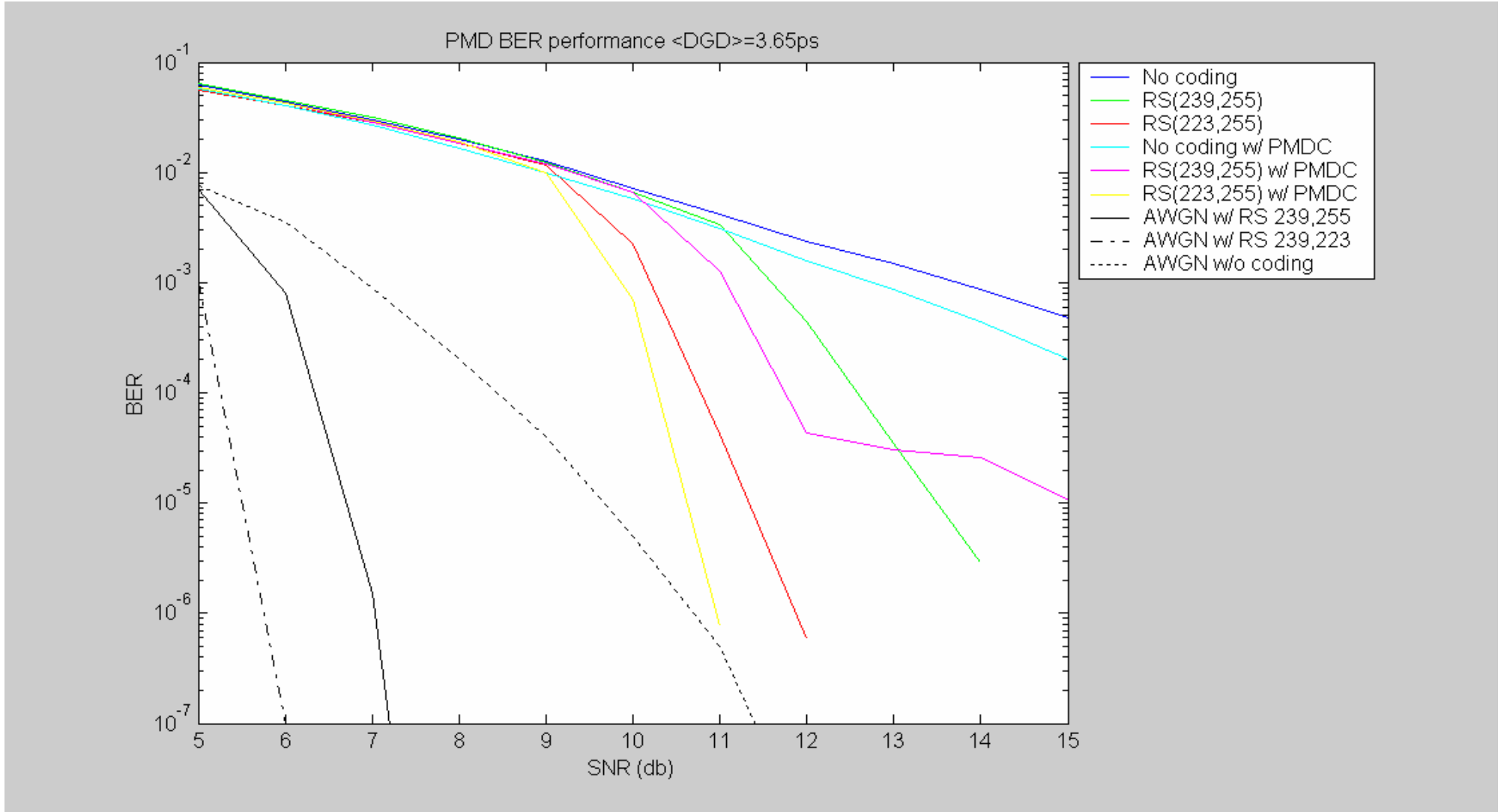
- PMD introduces ISI and reduces the SNR as well. When the DGD is small, ISI is less pronounced while SNR reduction is the major effect of PMD.
- The first order DGD is the main cause of the ISI, while the higher order PMD contributes to the SNR reduction as well as the ISI to a less extent.

PMD Compensator

(PSP transmission - 1st order compensator)

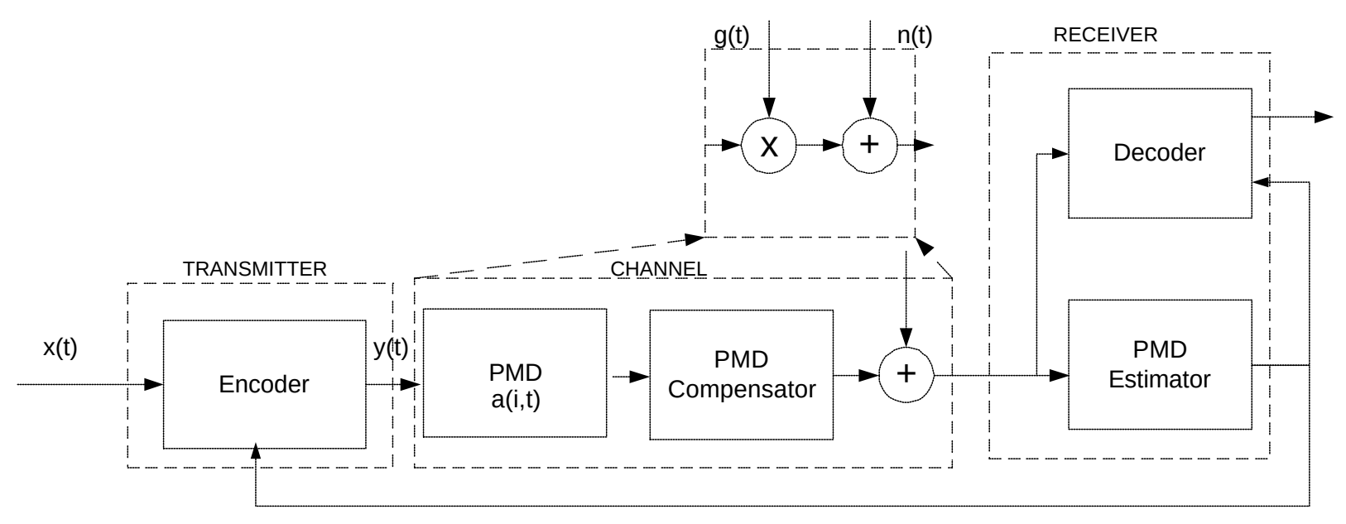


PMD Compensator and Coding

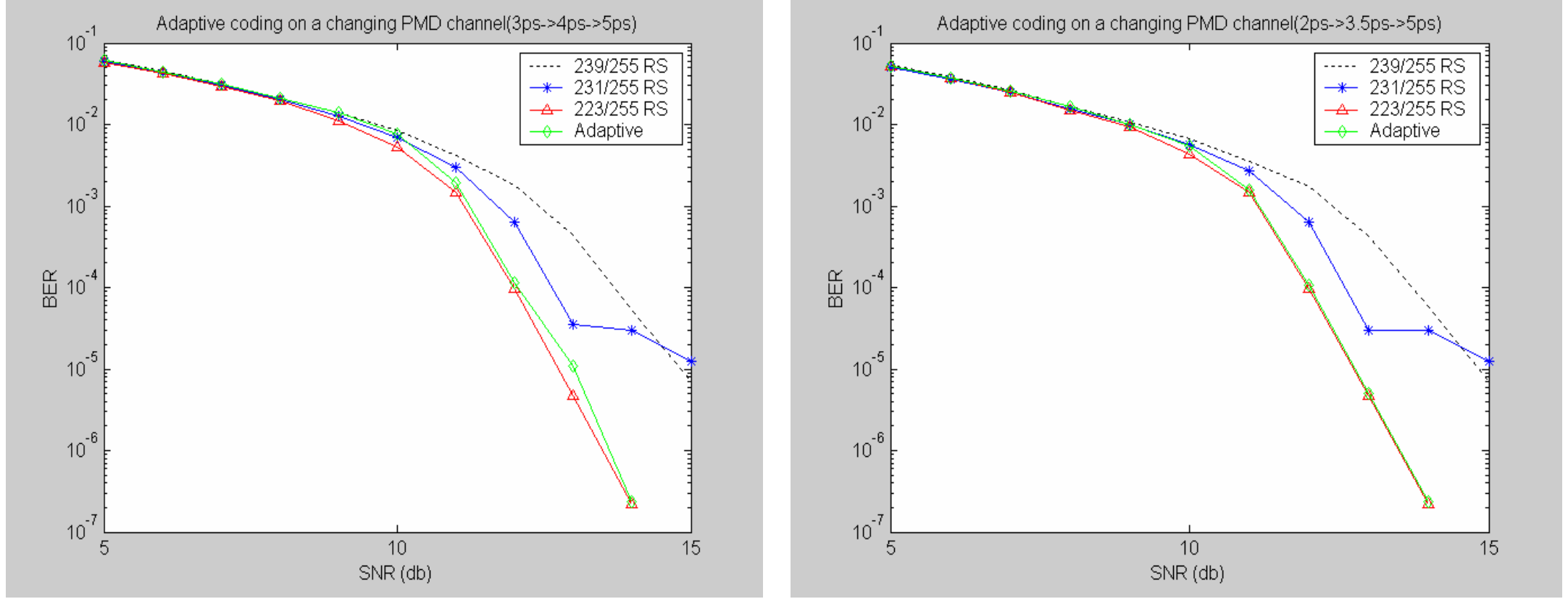


- By combining the FEC and optical PMD compensator (PMDC), significant BER improvement was shown in high DGD environments.
- RS codes themselves are less powerful in high DGD, low BER environments. But the introduction of the PMD compensator brings the operating environment to an area where the RS codes become powerful. Therefore the improvement is much better than the linear addition of improvements brought by FEC and compensator individually.

PMD Compensator and Adaptive Coding



- PMD-limited channel is time-varying and fades deeply when PMD is severe. Therefore the coding schemes have to be adaptive to be effective in real optical systems. Otherwise, the coding techniques which do not adapt to the fading PMD channel require a fixed low code rate to maintain acceptable performance in deep fades.
- Adaptive coding [3] is a very promising technique because of its prominent capability to maximize the channel performance and average throughput in time-varying fading channel such as PMD–limited channel.
- In the preliminary simulation, the code rate adaptation is based on known instantaneous channel update to both transmitter and receiver. As can be seen from the simulation results, the overall performance of the adaptive system is an improvement over all the individual coded tested. It approaches the performance of the strongest code (RS(255,223) in this case) in high SNR channel. Overall throughput is increased about 4%, which is significant in the bandwidth sensitive optical system.



References

[1] M. Karlsson, J. Brentel, and P. A. Andrekson, “Long-term measurement of PMD and polarization drift in installed fibers,” *J. Lightwave Technol.*, v. 18, pp. 941–951, July 2000.

[2] H. Sunnerud, C. Xie*,* M. Karlsson, R. Samuelsson, and P. A. Andrekson, “A Comparison Between Different PMD Compensation Techniques,” *J. Lightwave Technol.*, v. 20, pp. 368–378, March 2002.

[3] S. T. Chung and A. J. Goldsmith, “Degrees of freedom in adaptive modulation: a unified view,” IEEE Trans. on Comm., vol. 49, pp. 1561-1571, Sep. 2001.