SUBMISSION STEPS

☑ title
☑ ocis codes
☑ category
☑ author
☑ additional info
☑ abstract
☑ summary
☑ review my work

OFC 2003
OPTICAL FIBER COMMUNICATION
CONFERENCE & EXPOSITION

MESSAGE PROFILE HOME HELP

Currently Reviewing: Contributed, Control # 03-C-567-OFC

Thank you for your submission to 2003 OFC

This submission is complete. No further action is required. To edit any of your work, click on the desired step on the left side of this page.

Please note: if you remove any required information, this abstract may no longer be complete. After making any changes, please return to this summary by clicking "review my work" to confirm it is complete after all changes have been made.

1 Please complete all submission steps listed in the menu above.

2 To complete each step, make sure that you have entered information into all of the required fields and click the "Continue" button to save your work.

3 When you have completed your work, click on the "review my work" link above to verify that your submission is complete and appears the way you intend to submit it.

Summary:

Control/Tracking Number: 03-C-567-OFC
Activity: Contributed
Current Date/Time: 10/9/2002 1:56:13 PM

A comparative study of feedback controller sensitivity to all orders of PMD for a fixed DGD compensator

J. Zweck, S. Minkoff, A. Lima, I. Lima, C. Menyuk, University of Maryland Baltimore County, Baltimore, MD.

Introduction

Signal distortion due to polarization-mode dispersion (PMD) is an important limiting factor for long distance propagation in high-data-rate optical fiber communications systems. A simple device for mitigating the effects of PMD is an optical PMD compensator consisting of a polarization controller (PC) followed by a fixed differential group delay (DGD) element. Various feedback controllers have been used to optimize the performance of this compensator by adjusting the setting of the PC [1]-[3]. The performance of the compensator depends on how well the control signal is correlated to the eye opening and on the choice of optimization algorithm.

In this paper, we use numerical simulation to compare the performance of different feedback controllers for a fixed DGD compensator. For feedback we use the spectral lines of the received electrical signal at a quarter and a half of the bit rate [1] and the degree of polarization (DOP) ellipsoid [2], [4]. The DOP ellipsoid controller is attractive at very high data rates, and it eliminates the sensitivity fading that occurs with other feedback signals due to variations in the input polarization state. We compare these two experimentally-implemented feedback controllers to feeding back on the width of an isolated pulse. Although it cannot be implemented experimentally, the pulsewidth is highly correlated with the eye-opening penalty.

To compare the performance of the different controllers we calculate outage probabilities down to 10^{-5}. We show that the performance of the fixed DGD compensator varies widely depending on the choice of control signal [3]. To study the robustness of different controllers to higher-order PMD we investigate how the eye-opening penalty depends on the first- and second-order PMD. We extend the work in [3], [5] by providing an analysis of the DOP ellipsoid controller and by identifying the major reasons for the variation in the performance of the different controllers.

Simulation Methodology

Our results are for a noise-free 10 Gb/s nonreturn-to-zero (NRZ) signal with 16 bits and a rise time of 30 ps. For the DOP ellipsoid controller we maximize the length of the shortest principal axis of the ellipsoid. If the fiber only exhibits first-order PMD, this method minimizes the DGD [4]. To accurately generate the DOP ellipsoid we found that it is sufficient to use 38 initial polarization states that evenly cover the Poincaré sphere. To efficiently compute the DOP ellipsoid, we use a reduced representation of the signal consisting of the Jones vectors at 32 frequencies equally spaced over a 40 GHz bandwidth. The power spectrum of this signal is obtained by appropriately combining the spectrum of a single pulse with the carrier, ±10 and ±20 GHz side tones of the full time-domain representation of the signal. We use the full signal to evaluate the performance representation of the signal. We use the full signal to evaluate the performance of the compensator. When we use the reduced signal to compute the DOP ellipsoid, the results are in excellent agreement with results obtained using the full signal.

The performance of the compensator depends on the optimization algorithm. The objective function is the function of the PC rotation angles that is maximized by the controller. We incorporated the object-oriented optimization software package HCL [6] into our simulator and for this work we used HCL’s limited-memory BFGS (LMBFGS) algorithm with line search. The LMBFGS algorithm can be viewed as an extension of the conjugate gradient method in which additional storage produces accelerated convergence or as a restricted-storage version of standard quasi-Newton methods [7]. Once we have determined an appropriate direction in which to travel to increase the objective function, we apply a one-dimensional line search to find the best step length to take in that direction. Line searches allow local optimization methods to search for the global maximum [8].

To generate our results we used Monte Carlo simulations with multiple importance sampling applied to first- and second-order PMD, as in [9]. The transmission fiber was modeled using the coarse-step method with 80 birefringent sections, and we used the same 4x10^5 fiber realizations and the same initial PC setting for each controller. For each fiber realization the optimization algorithm searched for a single extremum of the objective function using a relative gradient stopping tolerance of 10^{-4}. We evaluated the performance using the eye opening, which we define to be the difference between the currents in the lowest mark and highest space at the clock recovery time. The eye-opening penalty is the ratio between the back-to-back and the PMD-distorted eye opening, and the outage probability is the probability that the eye-opening penalty exceeds a specified margin.

Results

To compare the controllers we used a transmission fiber with a mean DGD of $\langle|\tau|\rangle$ = 30 ps. We use the notation $\boldsymbol{\tau}$ for the polarization dispersion vector and $|\boldsymbol{\tau}|$ for the DGD of the transmission fiber. We found that the best choice for the for the DGD of the transmission fiber. We found that the best choice for the fixed DGD $|\tau_c|$ of the compensator depends on the choice of control signal. For each controller, we performed simulations for which $|\tau_c|/\langle|\tau|\rangle$ = 1.0, 1.5, 2.0 and 2.5. For the 5 GHz spectral line and DOP ellipsoid controllers the outage probability was smallest with $|\tau_c| = \langle|\tau|\rangle$. The pulse-width and 2.5 GHz spectral line controllers gave the best result with $|\tau_c| = 2.0\,\langle|\tau|\rangle$. In Fig. 1, we show the outage probability as a function of the eye-opening penalty for the different control signals using the best choices for $|\tau_c|$. The performance strongly depends on the choice of control signal. When the eye-opening penalty is 1 dB, the outage probability varies from $1.8\text{x}10^{-5}$ for the pulse-width control signal to $2.5\text{x}10^{-3}$ for the DOP ellipsoid controller.

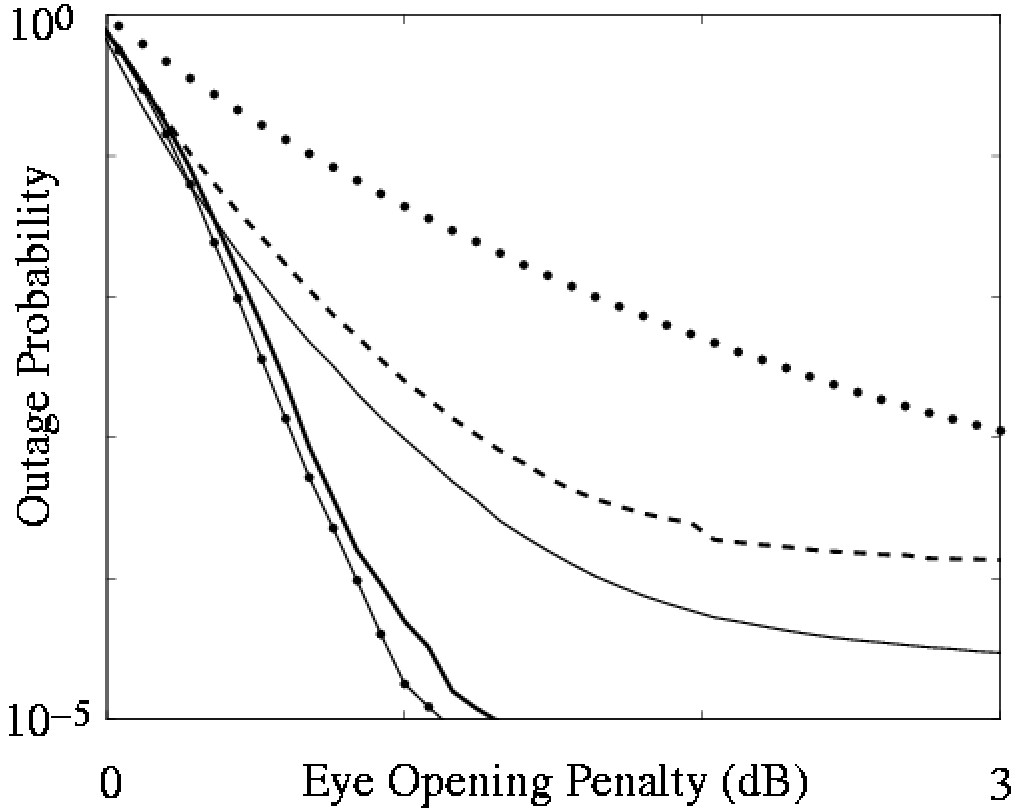

Fig. 1. Outage probability versus eye-opening penalty in dB. The curves show

(i) dots: uncompensated case;
(ii) dashed line: DOP ellipsoid with $|\tau_c| = \langle|\tau|\rangle$;
((iii) thin solid line: 5 GHz spectral line with $|\tau_c| = \langle|\tau|\rangle$;
(v) thick solid line: 2.5 GHz spectral line with $|\tau_c| = 2.0\,\langle|\tau|\rangle$;
(vi) dotted line: minimized pulsewidth with $|\tau_c| = 2.0\,\langle|\tau|\rangle$.

To understand the relative performance of the different controllers, in Figs. 2 and 3 we show contour plots of the conditional expectation of the eye opening penalty given values of $|\tau|$ and $|\tau_\omega|$, where the subscript ω denotes the derivative with respect to angular frequency and $\langle|\tau_\omega|\rangle$ = 520 ps^2. In Fig. 2 we see that for the 2.5 GHz spectral line with $|\tau_c|$ = 60 ps the average eye opening penalty is much less than without compensation, especially in the region about $|\tau|$ = 60 ps. Significantly, we find that with this control signal the fixed DGD compensator also compensates for higher-order PMD, even when $|\tau|$ = 0 and $|\tau_\omega|$ is large.

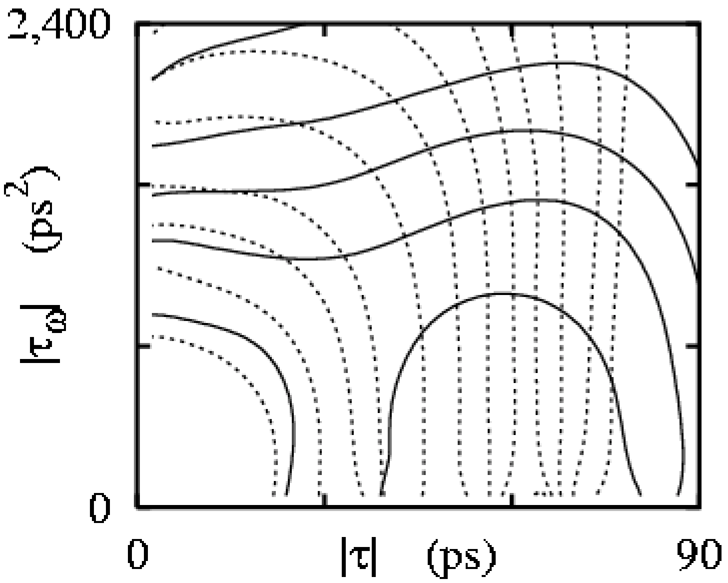

Fig. 2. Contour plots of the conditional expectation of the eye-opening penalty in dB given values of $|\tau|$ and $|\tau_\omega|$. Dashed lines are for the uncompensated system; solid lines are for the compensated system using the 2.5 GHz spectral line controller with $|\tau_c|$ = 60 ps. From left to right, the uncompensated contours are at

controller with $|\tau_c|$ = 60 ps. From left to right, the uncompensated contours are at 0.1, 0.2, 0.3, 0.4, 0.6, 0.8, 1.0, 1.2, 1.4, 1.7, 2.2, 2.8, and from bottom to top the compensated contours are at 0.1, 0.2, 0.3, 0.4, 0.6, 0.8, 1.0, 1.2.

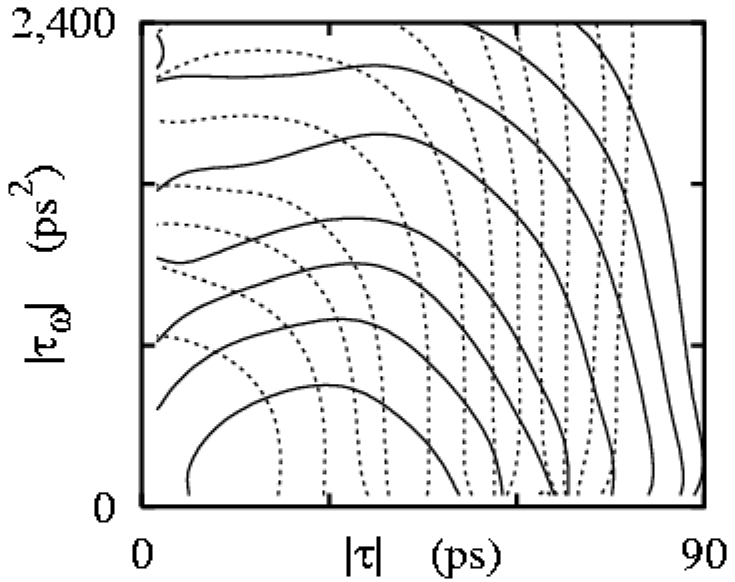

Fig. 3. The same as Fig. 2 but for the DOP ellipsoid controller with $|\tau_c|$ =30 ps.

We can use a first-order PMD model to explain why the performance is better with the 2.5 GHz than with the 5 GHz spectral line [2]. With only first-order PMD, the power in the 5 GHz tone has local maxima when the DGD is zero or 200 ps and a local minimum at 100 ps. Consequently, for the 5 GHz tone when $|\tau| > 100$ ps the total DGD exceeds 100 ps at the global maximum of the objective function. By contrast, the first local minimum of the 2.5 GHz tone occurs at 200 ps. For similar reasons the performance is poor with the 5 GHz spectral line when $|\tau_c| \geqslant$ 60 ps.

In Fig. 3 we show the conditional expectation for the DOP ellipsoid with $|\tau_c|$ = 30 ps. With only first-order PMD, when $|\tau_c|$ = 30 ps, the performance of the DOP ellipsoid controller is comparable to that of the spectral line controllers, since for the narrow-bandwidth NRZ signal the DOP ellipsoid feedback signal is a the narrow-bandwidth NRZ signal the DOP ellipsoid feedback signal is a monotonic function of the DGD [2], [4]. However, in Fig. 3 we see that the DOP ellipsoid does not perform well when higher-order PMD becomes significant, especially when $|\tau|$ is small. To understand this behavior, we examined the objective function for some of the fiber realizations with large $|\tau_\omega|$. We found that although the optimization algorithm usually located the global maximum, this maximum often corresponds to PC rotation angles that are up to 30° away from the angles that maximize the eye opening.

Conclusion

We compared the performance of different feedback controllers for a fixed DGD compensator using a local optimization technique globalized with a line search. We showed that the DOP ellipsoid does not perform well in the presence of significant higher-order PMD and that the quarter-bit-rate spectral line performs best in all regions of the first- and second-order PMD plane. Our results for the DOP ellipsoid controller also apply to a 40 Gb/s NRZ signal provided that all time parameters are scaled down by a factor of four.

References

[1] D. Sandel, M. Yoshida-Dierolf, R. Noe, A. Schopflin, E. Gottwald, and G. Fischer, *Electron. Lett.*, vol. 34, pp. 2258–2259, 1998.
[2] H. Rosenfeldt, Ch. Knothe, R. Ulrich, E. Brinkmeyer, U. Feiste, C. Schubert, J. Berger, R. Ludwig, H.G. Weber, and A. Ehrhardt, *Proc. OFC'01*, Anaheim, CA, 2001, paper PD27.
[3] J. Poirrier, H. Bulow, and F. Buchali, *Proc. OFC'02*, Annaheim, CA, 2002, paper WI3.
[4] J.M. Fini, P. C. Chou, and H. A. Haus, *Proc. OFC'01*, Anaheim, CA, 2001, paper WAA6.
[5] H. Sunnerud, C. Xie, M. Karlsson, R. Samuelsson, and P.A. Andrekson, *J. Lightwave Technol.*, vol. 20, pp. 368–378, 2002.
[6] M.S. Gockenbach, M.J. Petro, and W.W. Symes, *ACM Transactions on Mathematical Software*, vol. 25, pp. 191–212, 1999.
[7] D. Liu and J. Nocedal, *Mathematical Programming*, vol. 45, pp. 503–528,

1989.
[8] J. Dennis and R. Schnabel, *Numerical Methods for Unconstrained Optimization and Nonlinear Equations*, New Jersey: Prentice-Hall, Inc., 1983.
[9] S.L. Fogal, G. Biondini, and W.L. Kath, *Proc. OFC'02*, Anaheim, CA, 2002, paper ThA1.

Abstract:

A comparative study of the performance of different feedback contollers for a fixed DGD compensator shows that a spectral line control signal is more effective in the presence of higher-order PMD than a DOP ellipsoid controller.

Other Data Collected:

OCIS Codes (Complete): 060.2330 Fiber optics communications ; 060.2400 Fiber properties
Category (Complete): G - Subsys, Network Elements, Analog Sys
Additional Info (Complete):

Thank you for your submission. Click here for a timeline of the paper process.

This submission is complete. No further action is required.

Click here if you would like to have a confirmation of your submission emailed to you

---

✖ DELETE THIS SUBMISSION

For technical assistance, please click the Help button above. For Meeting information, please contact custserv@osa.org.