

Theoretical Modelling and Analysis on Trapping of Degree of Polarization in Compensation of Polarization Mode Dispersion

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Abstract— A theoretical model and its simulation to investigate degree-of-polarization(DOP) trapping in local area during compensation of polarization mode dispersion are presented and carried out. The simulation results show that occurrence of unwanted local DOP maxima and local ridges depends on condition of both differential group delay and incident angle of optical signal to input PSP of fiber link.

Keywords— Polarization mode dispersion(PMD), PMD compensation, Degree of polarization(DOP), Principal states of polarization(PSP), Differential group delay(DGD), Optical fiber communication

I. INTRODUCTION

Recent increase of per-channel bit rate to 40 Gb/s or beyond has made polarization mode dispersion(PMD) a crucial factor restricting performance of fiber-optic transmission system([1]-[5]). PMD refers to signal distortion owing to group delay difference between two orthogonal polarization modes in birefringent optical fiber link. A signal of shorter pulsewidth undergoes more distortion for a same birefringence of the link. Thus, the use of PMD compensator(PMDC) is inevitable in such a high-speed system([6]-[11]). The PMDC have used mainly DOP and RF power at half-clock frequency as a feedback signal for monitoring extent of signal distortion by PMD([6],[10]-[12]). One of the problems that make difficult deployment of PMDC in real field is occurrence of tracking error or unwanted trapping of feedback signal during compensation of PMD, which may worsen system performance than that without compensator since birefringence of compensator adds to the existing fiber link birefringence. Therefore, precise understanding and analysis on such trapping phenomenon is essential and can be used in finding a solution. In this paper, we present a theoretical model and simulate variation of degree of polarization(DOP) during PMD compensation to investigate and analyse its trapping phenomenon and characteristics.

II. MODEL FOR SIMULATION

Figure 1 shows a schematic diagram of the system model for simulation. Suppose in the model that a laser diode(LD) generates a monochromatic lightwave and a Mach-Zehnder Intensity modulator(MZIM) is driven in push-pull mode to produce an 40-Gb/s optical non-return-to-zero(NRZ) signal. A fiber link with first-order PMD has a differential group delay(DGD) and two different arbitrary input and output principal states of polarization(PSPs) on Poincare sphere which vary randomly due to environmental change such as temperature, pressure, and weather change. The link output field has the DGD between the two perpendicular output PSPs. Let a first-order PMD compensator be comprised of a polarization controller(PC), a differential delay line(DDL) producing differential delay time(DDT), a DOP meter, and a controller. The DDL composed of two polarization beam splitters(PBS) and a delay line between them is adjusted to provide inverse DDT to cancel DGD of the fiber link by the controller. The PC is controlled to transform and align two orthogonal output PSPs to the two PBS axes by the controller. The DOP meter obtains four Stokes parameters from the output field of the compensator to calculate DOP. The controller alternately controls the PC and the delay line by using conventional dithering algorithm in a direction to maximize DOP. In this scheme, complete compensation is achieved when DOP reaches one. The simulation was carried out by using an arbitrary bit sequence of 40-Gb/s NRZ-format data signal under various conditions of DGD, input and output PSPs, and DDT.

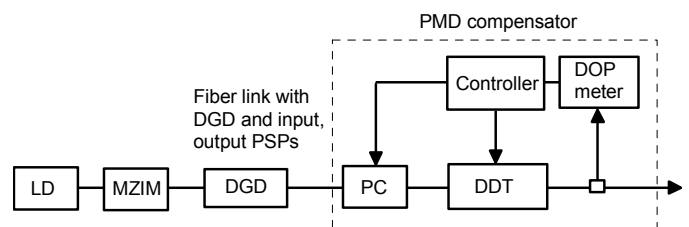


Figure 1. A schematic diagram of system model for simulation. MZIM: Mach-Zehnder Intensity Modulator, PC: Polarization Controller, DDT: Differential Delay Time.

III. SIMULATION RESULTS

Figure 2 shows DOP as a function of DGD and launch angle of source optical field to input PSP without PMD compensator. As can be seen in the Fig.2, for any given launch angle, DOP decreases as DGD increases. In particular, at 45-degree launch angle, DOP shows the largest slope of decline. For any given DGD, DOP varies with launch angle, and shows the smallest value at 45 and 135 degrees at which the signal pulse suffers worst distortion, whereas DOP has the largest value at 0, 90 and 180 degrees implying alignment of the source field to either of the two input PSPs and thus no signal distortion. For above 25-ps DGD, approximately constant DOP can be seen due to decorrelation effect of the signal.

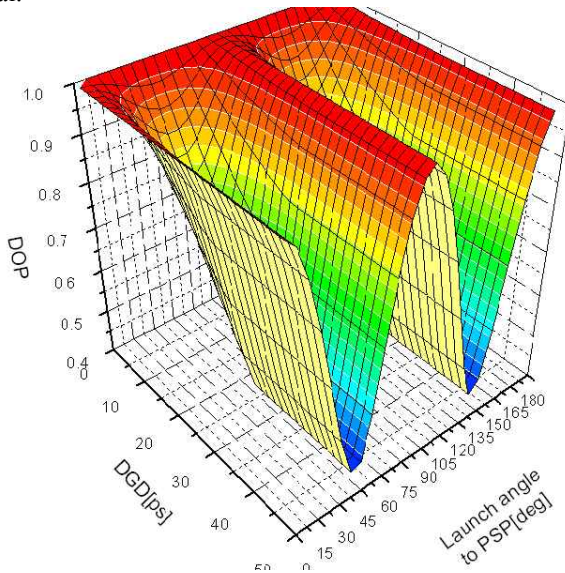


Figure 2. DOP versus DGD and launch angle to input PSP without PMD compensator.

Figures 3(a) and 3(b) show DOP variation in regard to DDT of PMDC and angle between output PSP and PBS axis, and an enlarged graph of one local maximum area when given 15-ps DGD and 20-degree launch angle to input PSP, respectively. As shown in the Fig. 3(a), the global DOP maximum of one implying complete compensation is found at 15-ps DDT and the angle of 0, 180 or 360 degree. These angles mean exact alignment of slow PSP to fast PBS axis and fast PSP to slow PBS axis. Unwanted local DOP maxima and ridges are found at 10-ps DDT and 70 or 250 degrees, where incomplete compensation and thus distorted output signal are obtained. If a current compensator state is around these local areas, DOP becomes trapped in local optimum location by tracking process of maximizing DOP. More specifically, if a PMDC state is in the angle region from 34 to 123 degrees or 214 to 303 degrees, the compensator is guided to and trapped in the above local maxima and ridges. Figure 3(b) shows a magnification of the local area in Fig. 3(a). If a PMDC current state is below 16.5 ps, DOP converges to the local maximum but otherwise moves up along the ridges. To escape from this trapping in this case, at least 45-degree abrupt angle rotation at a time by PC is found to be needed.

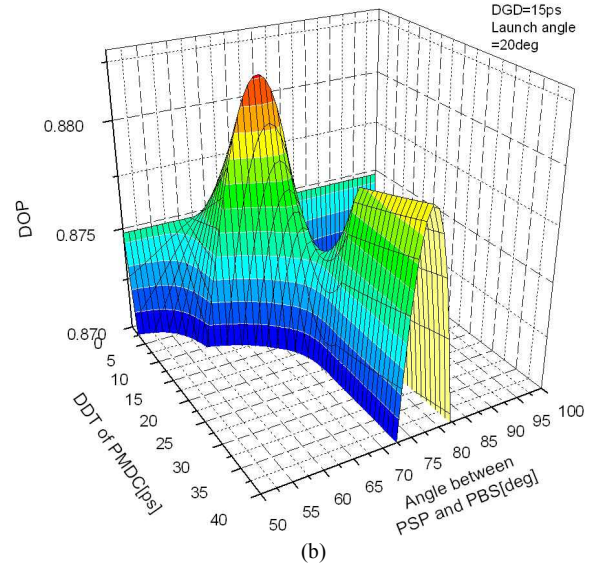
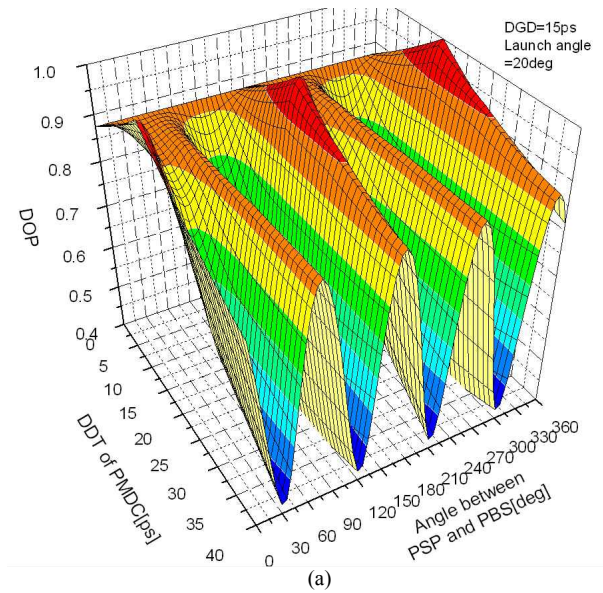


Figure 3. (a) DOP versus DDT of compensator and angle between PBS and PSP for 15ps DGD and 20degree launch angle. (b) One of enlarged local maximum areas of (a).

Figure 4 shows DOP with respect to DDT and angle between output PSP and PBS axis for a given 15-ps DGD and a 45-degree launch angle to input PSP which is the same condition except launch angle as in Fig. 3. No local DOP maxima or local ridges can be found as shown in Fig. 4. Therefore, wherever a current PMDC state is, DOP converges to a global maximum of one at 15-ps DDT and an angle of 0, 180, or 360 degree, meaning complete compensation and thus producing undistorted original pulse signal from the PMDC. It is found out that occurrence of local maxima and local ridges depends on the launch angle to input PSP although the same DGD is given.

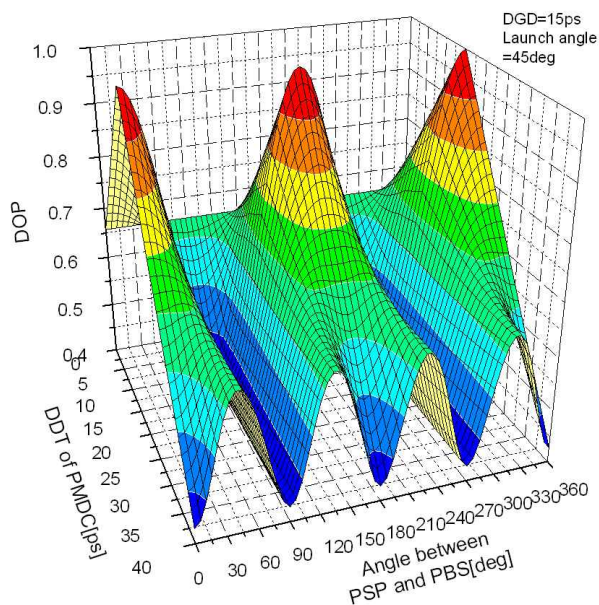


Figure 4. DOP versus DDT of compensator and angle between PBS and PSP for 15ps DGD and 45degree launch angle.

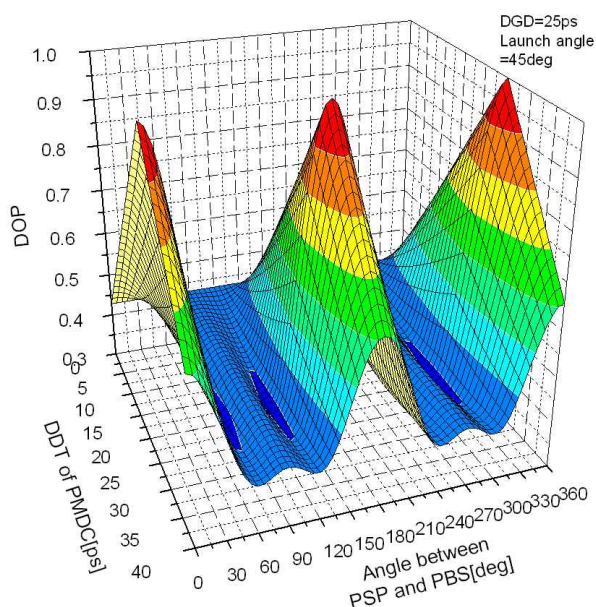


Figure 5. DOP versus DDT of compensator and angle between PBS and PSP for 25ps DGD and 45degree launch angle.

Figure 5 shows DOP as a function of DDT and angle between output PSP and PBS axis for a given 25-ps DGD and a 45-degree launch angle to input PSP. Compared to the condition in Fig. 4, only DGD value is changed from 15ps to 25ps. The results show that local DOP ridges are found between global DOP peaks. The global DOP maximum of complete compensation is located at a 25-ps DDT and an angle of 0, 180, 360 degrees. The local ridges exist along DDT over the angle regions of 64 to 116 and 244 to 296

degrees. When a compensator state is in these angle regions, DOP is moved toward the local ridges and trapped there. It is also found out that whether local maxima or ridges exist or not relies on the DGD of fiber link although given the same launch angle to input PSP. To escape from the local ridge in this case, at least 27-degree sudden angle rotation at a time by PC is found to be needed, which is smaller than that in the case of Fig. 3.

IV. CONCLUSIONS

A theoretical model and the simulation for investigating and analysing characteristics and local-area trapping phenomenon of degree of polarization(DOP) during PMD compensation using conventional dithering tracking process were presented and performed. The simulation results showed that occurrence of unwanted local DOP maxima and local ridges while operating PMD compensator depends on both DGD of fiber link and launch angle of an optical signal to input PSP. For a same DGD given, local maxima and local ridges were found to occur or not occur depending on the launch angle, and vice versa. Whether a PMD compensator suffers local DOP maxima or not appears to rely on the extent of signal depolarization caused by both fiber link and the compensator during compensation. It was found out that to extricate the compensator from the trapping in the local DOP maxima and ridges, an abrupt large angle rotation of output PSP at a time by a polarization controller is needed and its angle size depends on the DGD and the launch angle to input PSP.

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