Chapter 4

WDM/PolSK Fiber Communication System

In this chapter, we will utilize the base principle such as extruding and bending to create the birefringence within the fiber. However, apply this principle to modulate the polarization state of transmission signal. In general, various causes can distort the SOP during transmission. However, in contrast to the waveform modulation schemes discussed earlier (i.e. phase, frequency and amplitude modulation), PolSK transmits information by modulating the state of polarization (SOP) of the light carrier. Thus, for accurate detection, it is important to maintain the SOP in transmission. From the above reasons, we know that it is necessary to use compensator [73-79] or polarization controller in PolSK transmission [80-83].

Therefore, we design the compensator to reduce the impact of the PMD. We know optical pulse broadening due to PMD. However, when the pulses broaden as they travel along the fiber and start to spread and overlap each other, the data can become seriously corrupt. Besides, the value of DOP is an important parameter to express the transmission ratio. Because, the signal of degree of polarization (DOP) is not only affected by PMD, but also by various factors, such as the modulation format, fiber non-linearity and so on. Beside, the unstable environment is a main factor made the polarization variation with time. Therefore, if the variation of external environment is reduced, the value of DOP will be raised. Therefore, in the section 3.2 and 3.3 we will describe the variation of polarization state and DOP in long haul and short haul transmission without/with compensated by our homemade compensator. Finally, we will simulate the results of eye pattern and BER with/without compensated and analyze the relationship eye pattern and BER with transmission distance.

4-1 Introduction

General single mode fibers support two polarization modes of the original signal. In an ideal world, perfect fibers with geometrical uniformity, homogeneous material, and no tension effects, would propagate these polarization modes at exactly the same speed. In the real world, however, fibers are far from being perfect and, consequently, polarization modes travel at slightly different speeds. This difference in speed translates into a difference in transmission time through the fiber system, which is known as a differential group delay (DGD) [84-88]. When this parameter is averaged and normalized by the square root of the fiber’s length, it is called a PMD coefficient ($ps/\sqrt{km}$). [89-93] PMD creates a closing of the receiver’s eye diagram, which increases the bit error rate (BER) [94-100]. However, the value of DOP also be reduced, because it is influenced by the PMD and external environment. Therefore, the transmission ratio will be reduced. In order to eliminate those factors and raise the transmission ratio, we need a compensator.

In modern optical fiber communication system, polarization mode dispersion (PMD) is increasingly becoming a serious limitation to the transmission rate. Consequently, Polarization Mode Dispersion (PMD) has played a leading role in long-distant fiber transmission. When the distance for fiber communication gets longer, PMD will accordingly be more apparent, and the distortion of signal will consequently become more serious. However, this leads to degradation in system performance. The PMD of installed fibers fluctuates with time due to environmental influences, for example changes in temperature and stress. Besides, for the fiber communication systems installed several years ago, the fibers are single mode fibers with rather large PMD values. Therefore, in these fiber communication systems, it is impossible to overcome the internal and external factors, and then upgrade the transmission rate in those systems without compensator [101-110].

When the laser source on the transmission, the polarization state will become unstable and vibrate serious. Because on the process of transmission, those environment factors such as vibration, temperature and stress by external force all influence the polarization state. Those variations of external environment cause the error of transmission results. Therefore, all factors above will influence the proportion of PMD and then affect the quality of fiber transmission, indirectly. Besides, the bit error rate (BER) will be raised and data transmission rate will be decreased. Besides, we can observe the variation of degree of polarization (DOP) and ellipticity. Because they influence the value of transmission rate. Therefore, in order to raise the value of DOP and reduce the variation of polarization state we design a compensator. It can effective reduce the external force influence and promote the transmission ratio.

4-2 Using PZT to Modulated The Polarization State of Our WDM system

In our asymmetrical resonator laser system, the polarization states are differences between two peak lasers and those polarization states are changed by adjusting the bias voltage of E/O switch, those characteristics are described in chapter2. From chapter2, we find that when the bias voltage of E/O switch is 3V, the condition of lasing power is the best. Therefore, in this modulated transmission system, we will utilize this condition to analyze the modulate state.

In our experimental structure, the current of SOA is about 117.5mA and the bias voltage of E/O switch is 3V, we know the initial polarization states are different of λ_1, λ_2, λ_3, λ_4. Therefore, in order to get the same polarization direction we utilize the method of squeeze to change the internal structure of the signal mode fiber, the experimental structure is shown in Fig.4-1. We use squeezer (PZT) to reach the effect of the polarization analyzer and control the polarization state to the position that we want. The squeezers component two parts, we define first squeezer P_1 and second squeezer P_2. First, we control the polarization of λ_1 and λ_2 to the positions (A, B, C, D) of (0,0,1), (0,-1,0), (0,0,-1) and (0,1,0) on the

Poincaré sphere, respectively. The diagram is shown in Fig.4-2. However, if we want to control the polarization states of λ_1, λ_2, λ_3, λ_4 to the A position, the PZT squeeze depth need to P_1=0.043mm and P_2=0mm, P_1=0.17mm and P_2=0mm, P_1=0.13mm and P_2=0.15mm, P_1=0.38mm and P_2=0mm at λ_1, λ_2, λ_3, λ_4, respectively and the control results are shown in Fig.4-3 (a), Fig.4-4 (a), Fig.4-5(a) and Fig.4-6(a). Symmetrical to the B position, the PZT squeeze depth need to P_1=0.043mm, P_2=0.003mm, P_1=0.03mm, P_2=0mm, P_1=0.13mm, P_2=0.38mm, P_1=0.27mm, P_2=0mm, respectively, the results are shown in Fig.4-3 (b), Fig.4-4 (b), Fig.4-5 (b) and Fig.4-6 (b). However, to C position When P_1 = 0.043mm, P_2 = 0.015mm the polarization state at λ_1 can controlled to C position, the result is shown in Fig.4-3 (c). However, controlled the polarization state at λ_2, λ_3, λ_4 to C position the P_1, P_2 should be equaled to 0.03mm, 0.042mm, 0mm, 0.46mm and 0.12mm, 0.09mm, the result are shown in Fig.4-4 (c), Fig.4-5 (c) and Fig.4-6 (c). Symmetrical to the D position of λ_1, the PZT squeezers P_1 need to 0.097mm and P_2 = 0mm, the result is shown in Fig.4-3(a). However, to the D position of λ_2, λ_3, λ_4 the P_1, P_2 need to 0.03mm and 0.056mm, 0mm and 0.19mm, 0.12mm and 0.22mm, respectively. The result is shown in Fig.4-4 (d), Fig.4-5 (d) and Fig.4-6 (d).

4-3 The Experimental Result of WDM Polarization Shift Keying in 100km Transmission

In this section we utilize PZT to modulate the laser source, the laser source is the asymmetrical resonator laser this is described in chapter2. The modulation of the state of polarization of a light-wave or polarization shift keying (PolSK) has been recently proposed for digital optical transmission. PolSK transmission encodes information on a constellation of signal point in the space of the Stokes parameters. In this section we will describe 4-PolSK and applied it to the WDM transmission system in the short-distance and long-distance transmission. The output SOP in general fluctuate randomly, but the orthogonality between orthogonal input state is preserved [113-114]. Therefore, the only influence of the monomode optical fiber is a rigid rotation of the signal point constellation in the Stokes space. However, the Poincaré sphere can be used to represent the polarization states of partially polarized fields and to show how this presentation is useful in the analysis and measurement of partially polarized waves.

The fluctuation of the received field SOP caused by fiber birefringence is compensated using either polarization tracking algorithms or electro-optic control. Therefore, in order to compensate and steady the polarization state on the Poincaré sphere we made a compensator. We put the homemade compensator in the receiver, the experimental structure is shown in Fig.4-7. In this section, we observe the variation of DOP and ellipticity with/without our homemade compensator in the short-distance and long-distance transmission.

After modulate the polarization state of transmission source by PZT, we utilize DMUX to demodulate, the structure of our system is shown in Fig.4-8. First, we utilize the method of PZT to modulate the polarization state at A, B, C, D four positions, then utilize MUX to demodulate and transmission 100Km. When the light source through the transmission of 3m, the polarization state will be influenced on the external environment. Therefore, the polarization will become vibration and unstable with time. However, this phenomenon will cause the error of receiver point, so we think up a method to compensate this phenomenon. We utilize four channels fiber-squeezer and with our devise circuit to constitute the automatic compensator.

We apply our homemade compensator to the WDM/polarization shift keying system. First, we modulate the initial polarization at A position the initial results are shown in Fig.4-8(a) and Fig.4-8(b), then through DMUX and 100Km transmission the polarization state become unstable and diverge from the initial position, the result is shown in Fig.4-8(a). Therefore, we utilize the compensator to compensate the polarization state the result is shown in Fig.4-8(b). Compare the Fig.4-8(a) and Fig.4-8(b), we can find the polarization state with compensated is more stable than without compensated. The variation of orientation with/without turn on the compensator is shown in Fig.4-9. The variation of orientation without compensated reach 24°, but through compensated the variation is reduced to 6°. We also measure and compare the degree of polarization (DOP) and ellipticity with /without turn on our compensator, the results are shown in Fig.4-10 and Fig.4-11. From those results, we can find the compensator reduces the variation of the DOP and the average value of DOP can be raised from 47.25% to 80.48%. However, the variation of ellipticity also be reduced from 12.5° to 6°.

We use the equally theory to compensate the different polarization state such as B, C, D positions. First, we turn on the compensator and compare the polarization state with/ without compensated of through the 100Km transmitted. The without/ with compensation results of B position are shown in Fig.4-12(a) and Fig.4-12(b). From this result we can obvious observe the variation of polarization state can be reduced, therefore we can effective stable the polarization state of distance transmission. Compare the variation of polarization orientation with/without compensated, the result is shown in Fig.4-13. And the measured results of DOP and ellipticity are shown in Fig.4-14 and Fig.4-15. The value of DOP can be raised from 48.07% to 81.25%, it symbolize the percentage of polarization compared to the total average power of the optical signal. Therefore, the value of DOP is larger express the transmission rate better. However, the variation of ellipticity reduced form 16.7° to 10.2°.

However, the C position the compensator also compensate the external influence, the polarization state is more stable with compensated than without compensated, the results are shown in Fig.4-16(a) and Fig.4-16(b). Those results express the variation of orientation can be effective reduced, we generalize the relationship curve is shown in Fig.4-17. Then, we also measure the variation of DOP and ellipticity, the value of DOP can be raised from 51.47% to 83.42% and the valuation of ellipticity can be reduced form 11.3° to 3.21°. The experimental results are shown in Fig.4-18 and Fig.4-19. Symmetrical at D position the polarization state can be effective stabled, the results of polarization state with/without turn on the compensator are shown in Fig,4-20(a) and Fig.4-20(b). From observe the variation of polarization orientation, we find the variation of orientation can be reduced from 22° to 10°, the result is shown in Fig.4-21. However, DOP also be stabled and the value be effective raised the compensated results are shown in Fig.4-22 and Fig.4-23. The value of DOP can be raised form 47.47% to 77.23% and the variation of ellipticity can be restrained form 18° to 9°, respectively. From those results, we can effective restrain the variation of external environment and raise the transmission ratio. Our homemade can be applied on the optical transmission system, it will compensate the PMD and restrain the influence of external force, temperature and press. Therefore, the transmission ratio can be effective raised.

In the next transmission system, we utilize filter to measure the compensation result in the channel1at A, B, C, D positions, respectively.

The experimental structure is shown in Fig.4-24. From Fig.4-25 (a) and Fig.4-25(b), we find the polarization trajectory of uncompensated is vibrating seriously, but when we turn on the compensator, the vibration of polarization state can be effective restrained, the relationship with orientation with/without compensated is shown in Fig.4-26 . Besides, the value of DOP also can be raised from 51.45% to 75.68%, and the variation of ellipticity can be reduced from 12° to 7°, the results are shown in Fig.4-27 and Fig.4-28. The condition of above describe is switching the position to A point. When the switch position from initial position to B point, the compensated result also be successful, the experimental results with/without turn on our homemade compensator are shown in Fig.4-29(a) and Fig.4-29(b) and the variation of orientation is shown in Fig.4-30. From those results, we find our homemade compensator can effective compensate the polarization state. Besides, the value of DOP can be effective from 56.78% to 71.89% and the vibration of ellipticity can be reduced from 23° to 14°, the results are shown in Fig.4-31 and Fig.4-32. We use the equally theory to compensate the different switch position such as C, D positions. At C position, the variation of polarization state with/without compensated is shown in Fig.4-33(a) and Fig.4-33(b). The variation of orientation is shown in Fig.4-34. However, the value of DOP can be raised from 57.95% to 78.94%, the result is shown on Fig.4-35 and variation of ellipticity is from 7° to 3°, The result is shown in Fig.4-36. At last, we discuss the compensate result when switch position is from initial to D point, the result with/without compensated is shown in Fig.4-37(a) and Fig.4-37(b).

The variation of orientation with/without compensated is shown in Fig.4-38. However, the variation of DOP with/without is shown in Fig.4-39, from this result we find the value of DOP can be raised from 52.97% to 73.26%. The variation of ellipticity can be reduced from 23° to 13°, the result is shown in Fig,4-40.

4-4 Summary

In this chapter, we applied our homemade compensator to the WDM system. We effective restrain the environment factors such as vibration, temperature and stress and raise the value of DOP. The randomly polarization state plays a fundamental role in the transmission limitation of the data rate, affecting not only coherent systems but also direct detection systems. Especially the effect of the randomly environment and other pressure factors are all bring the polarization variation instantaneously. Therefore, in the transmission system how to stable polarization and overcome those best factors become very important. In our experimental results we can obviously observe the variation of DOP and ellipticity be effectively reduced by our homemade compensator.

We can effectively restrain PMD, nonlinear and the other best phenomenon in the long distance transmission using our homemade polarization compensator. The compensator can compensate the variation of ellipticity less than 3°and the best performance of the DOP is 78.94%.

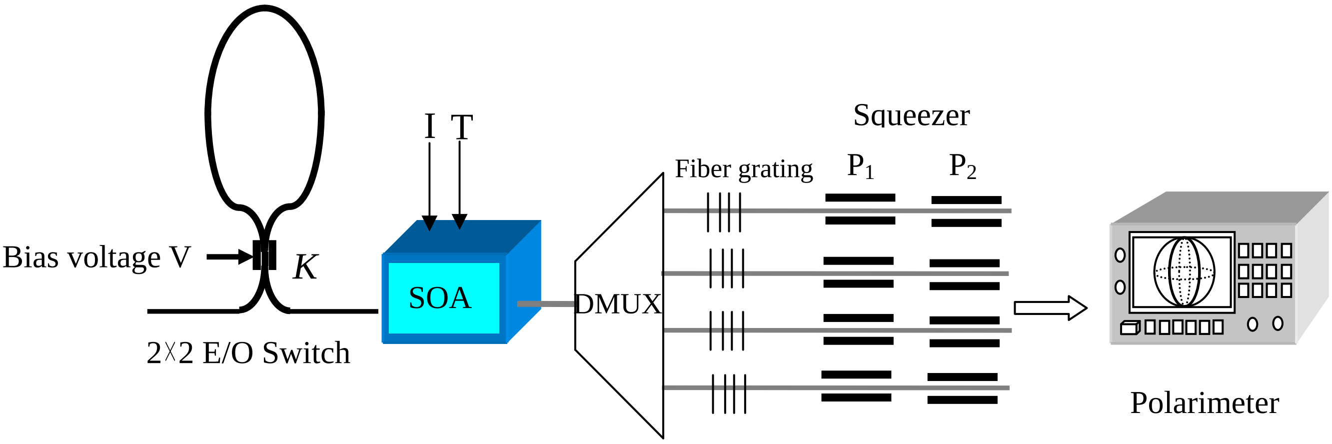


Fig.4-1 The structure of WDM modulation system

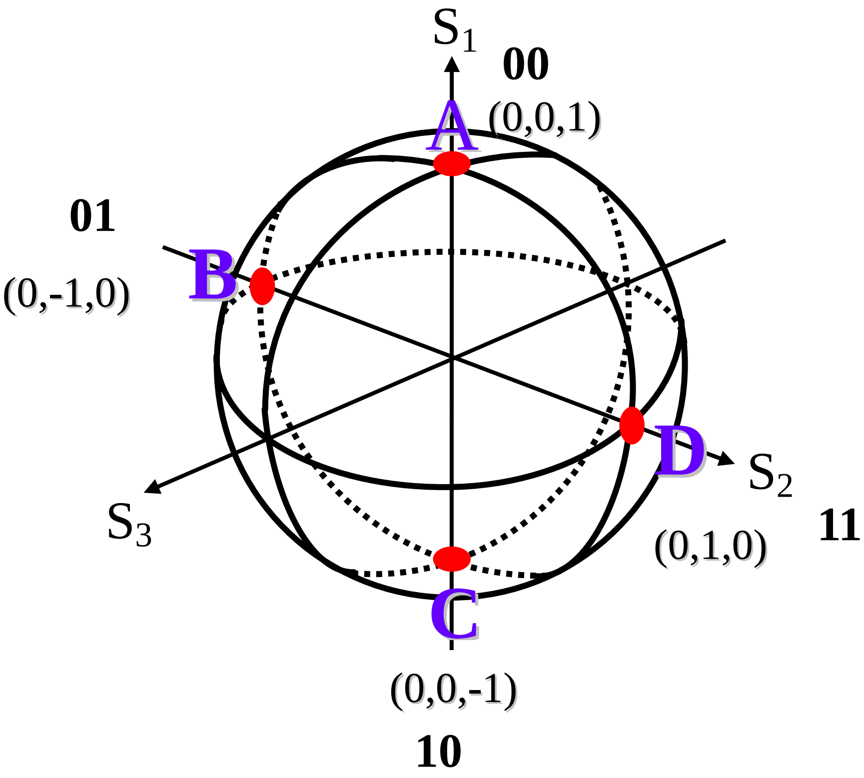
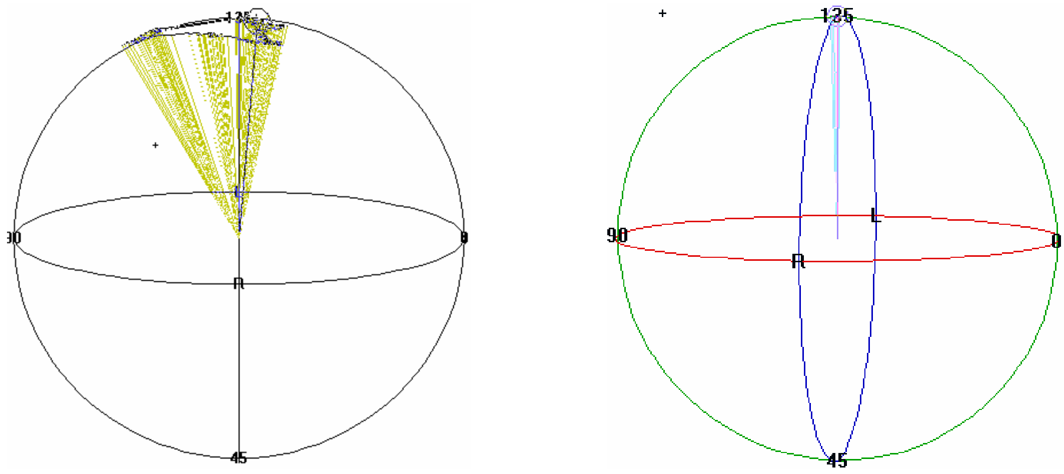


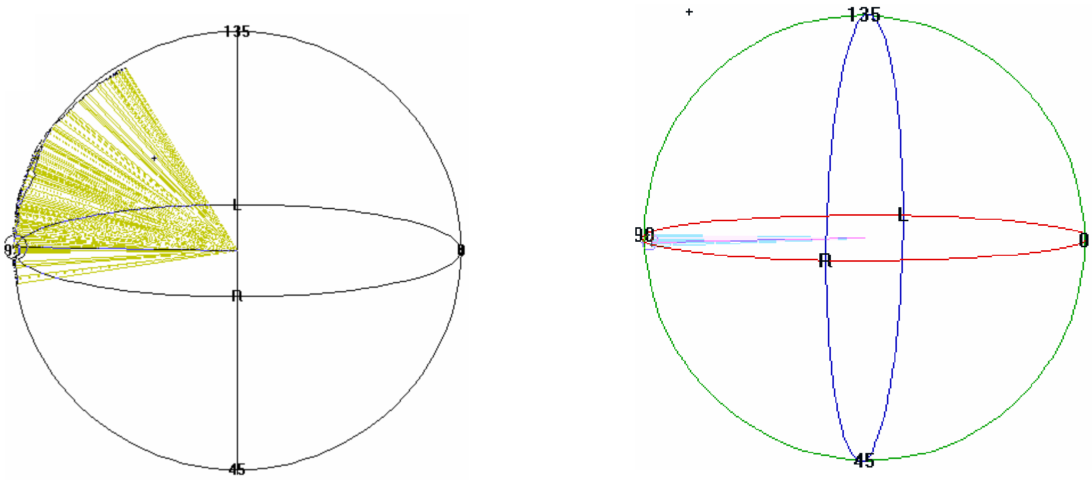
Fig.4-2 The schematic diagram of polarization state on the poincáre sphere



Squeeze depth P_1=0.043mm
Squeeze depth P_2 =0mm

The stability at position A

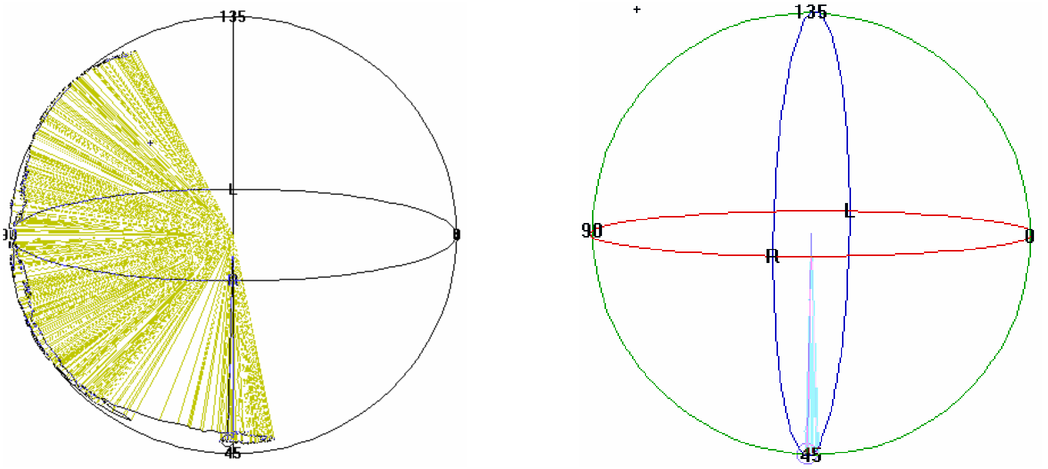
Fig.4-3 (a) Modulating the polarization state from original position to A position by PZT at λ = 1301.92nm



Squeeze depth P_1=0.043mm
Squeeze depth P_2=0.003mm

The stability at position B

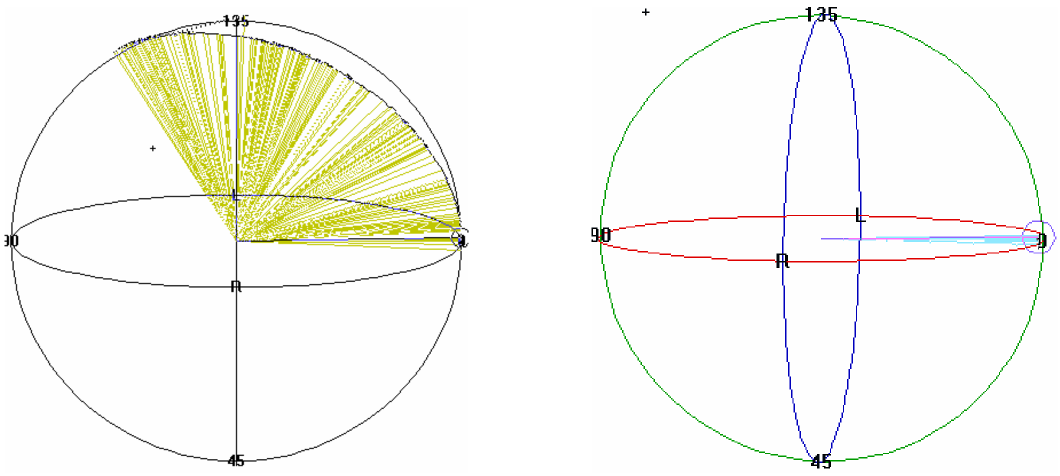
Fig.4-3 (b) Modulating the polarization state from original position to B position by PZT at λ = 1301.92nm



Squeeze depth P_1=0.097mm
Squeeze depth P_2=0mm

The stability at position C

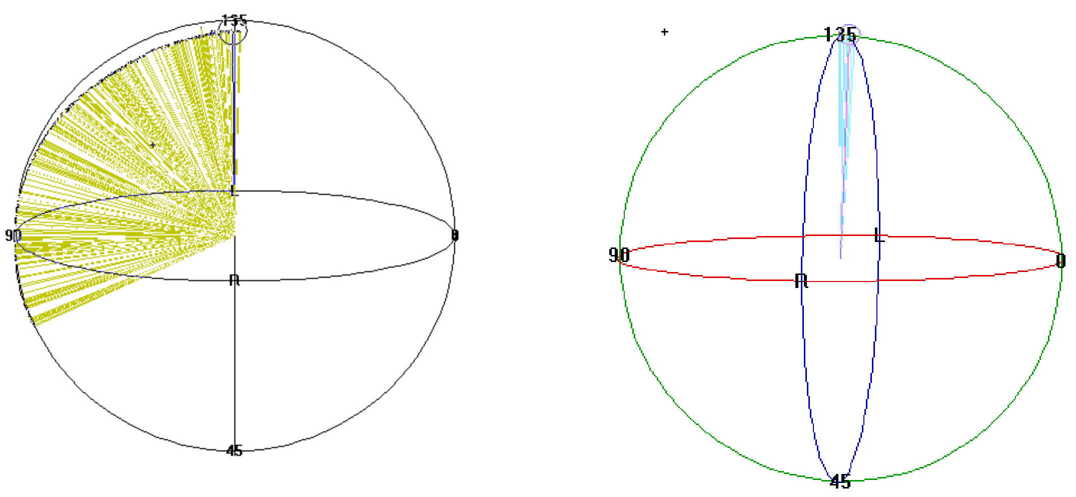
Fig.4-3 (c) Modulating the polarization state from original position to C position by PZT at λ = 1301.92nm



Squeeze depth P_1=0.043mm,
Squeeze depth P_2=0.015mm

The stability at position D

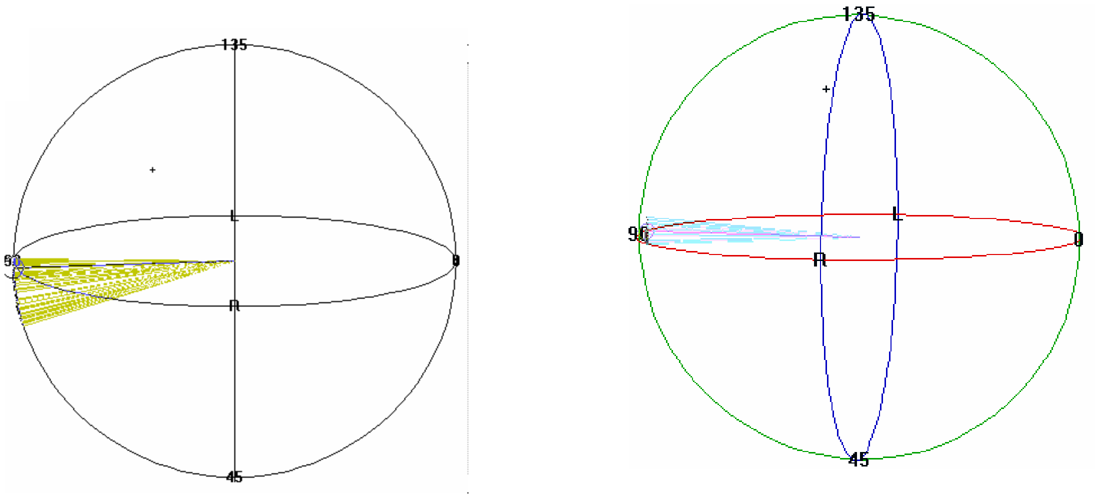
Fig.4-3 (d) Modulating the polarization state from original position to D position by PZT at λ = 1301.92nm



Squeeze depth P_1= 0.17mm
Squeeze depth P_2 =0mm

The stability at position A

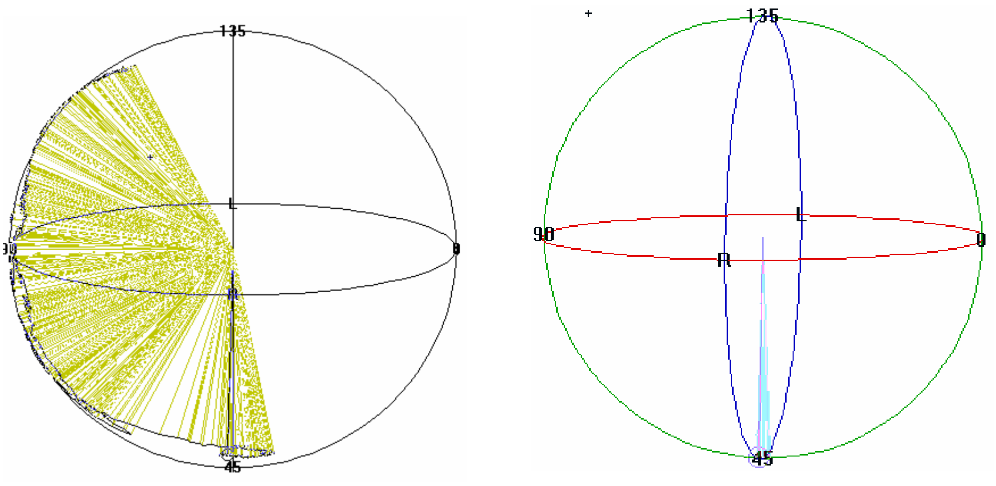
Fig.4-4 (a) Modulating the polarization state from original position to A position by PZT at λ=1318.2nm



Squeeze depth P_1=0.03mm
Squeeze depth P_2 =0mm

The stability at position B

Fig.4-4 (b) Modulating the polarization state from original position to B position by PZT at λ=1318.2nm



Squeeze depth P_1=0.03mm,
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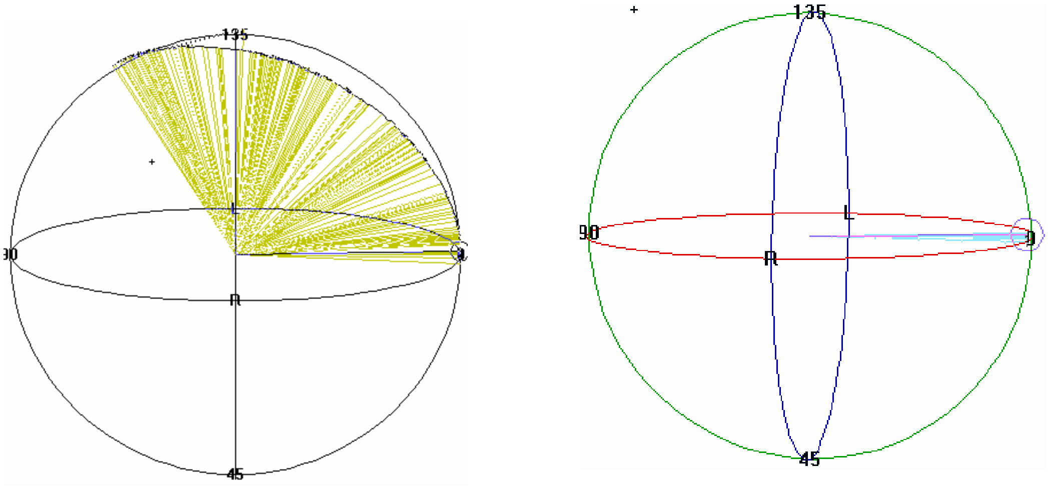
The stability at position C

Fig.4-4 (c) Modulating the polarization state from original position to C position by PZT at λ=1318.2nm



Squeeze depth P_1=0.03mm,
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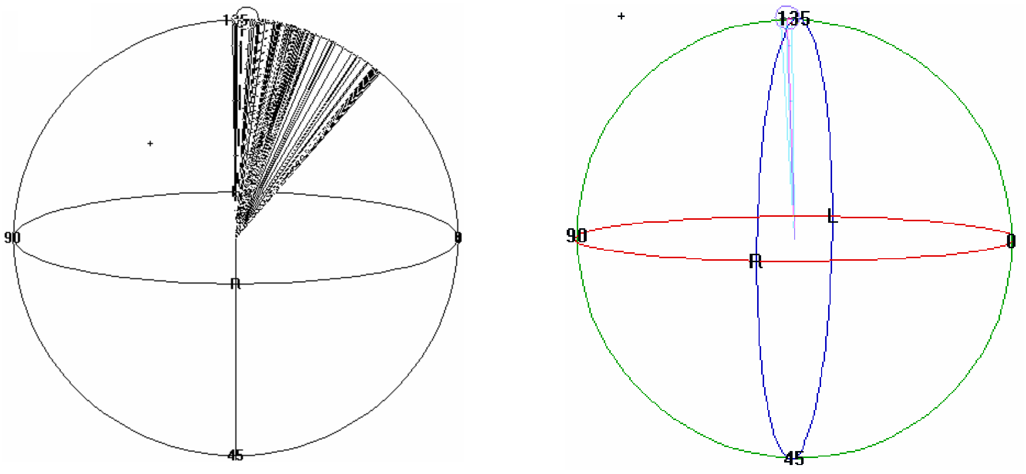
The stability at position D

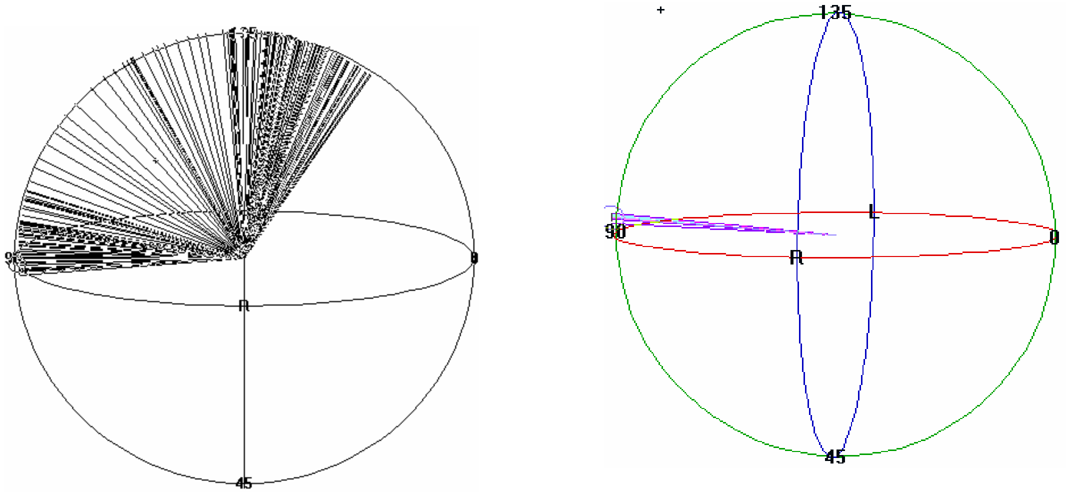
Fig.4-4 (d) Modulating the polarization state from original position to D position by PZT at λ=1318.2nm



Squeeze depth P_1=0.13mm,
Squeeze depth P_2= 0.15mm

The stability at position A

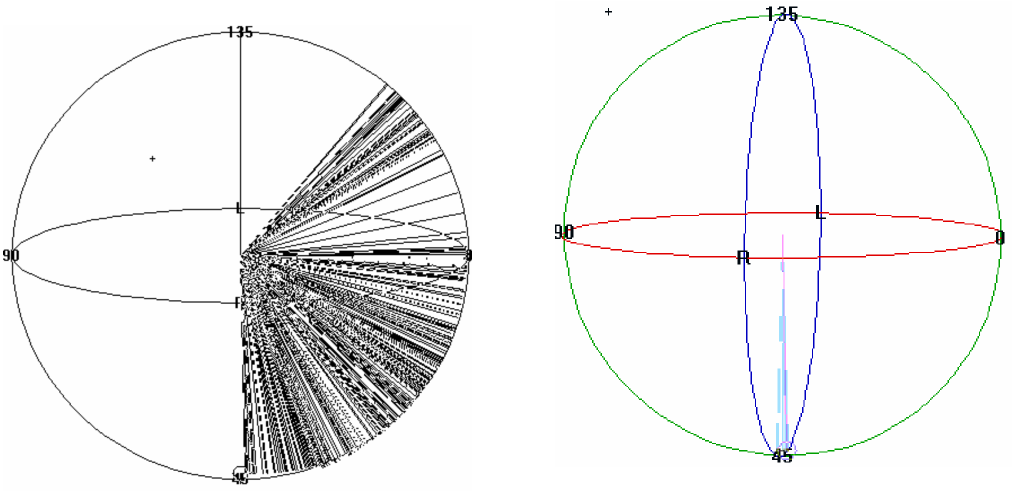
Fig.4-5 (a) Modulating the polarization state from original position to A position by PZT at λ=1325.82nm



Squeeze depth P_1=0.13mm,
Squeeze depth P_2=0.38mm

The stability at position B

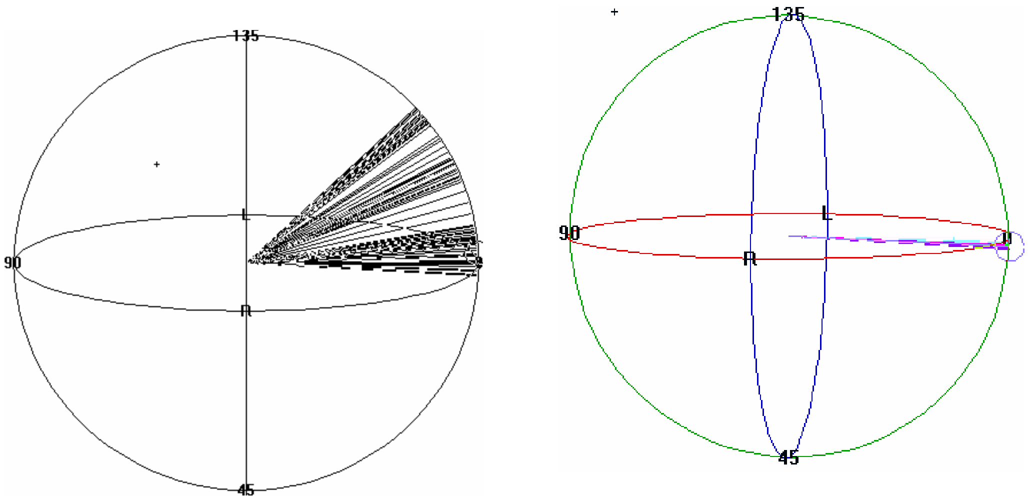
Fig.4-5 (b) Modulating the polarization state from original position to B position by PZT at λ=1325.82nm



Squeeze depth P_1=0mm,
Squeeze depth P_2= 0.46mm

The stability at position C

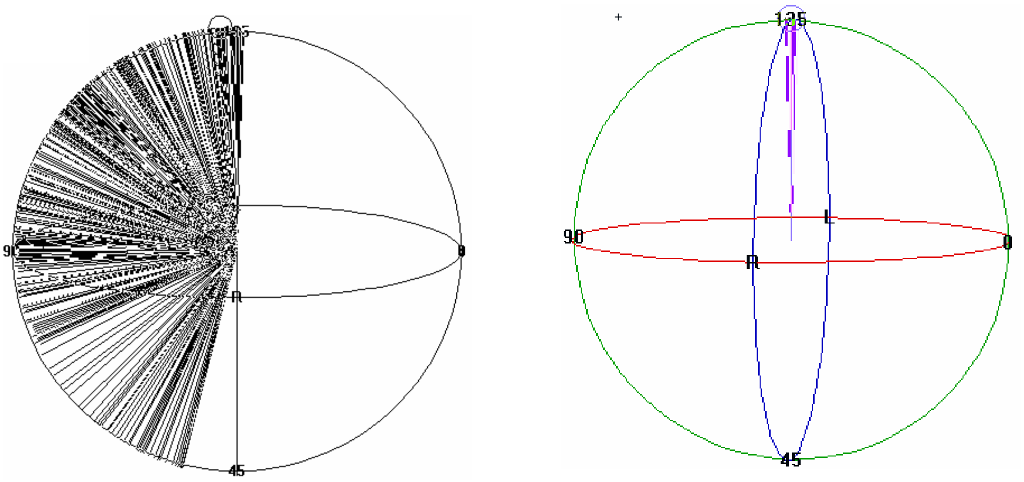
Fig.4-5 (c) Modulating the polarization state from original position to C position by PZT at λ=1325.82nm



Squeeze depth P_1=0mm,
Squeeze depth P_2=0.19mm

The stability at position D

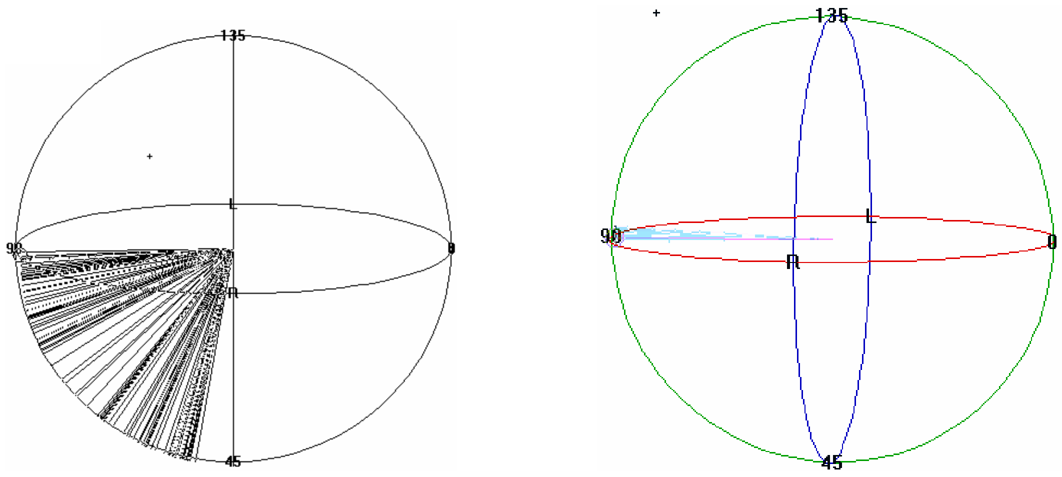
Fig.4-5 (d) Modulating the polarization state from original position to D position by PZT at λ=1325.82nm



Squeeze depth P_1=0.38mm,
Squeeze depth P_2= 0mm

The stability at position A

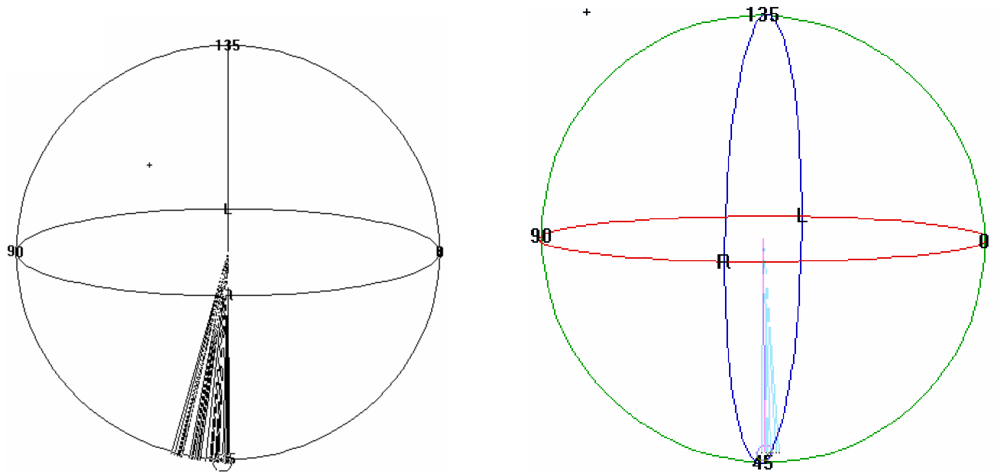
Fig.4-6 (a) Modulating the polarization state from original position to A position by PZT at λ=1330.12nm



Squeeze depth P_1=0.27mm,
Squeeze depth P_2=0mm

The stability at position B

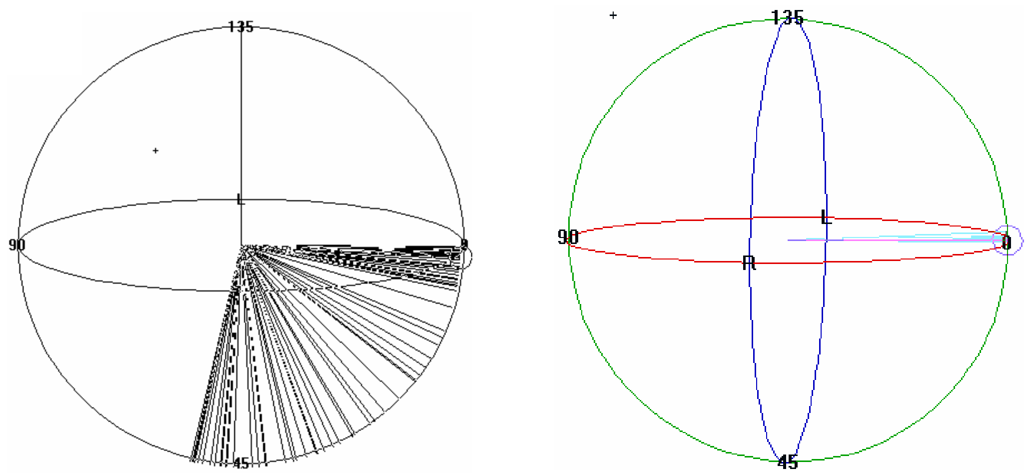
Fig.4-6 (b) Modulating the polarization state from original position to B position by PZT at λ=1330.12nm



Squeeze depth P_1=0.12mm,
Squeeze depth P_2= 0.09mm

The stability at position C

Fig.4-6 (c) Modulating the polarization state from original position to C position by PZT at λ=1330.12nm



Squeeze depth P_1=0.12mm,
Squeeze depth P_2=0.22mm

The stability at position D

Fig.4-6 (d) Modulating the polarization state from original position to D position by PZT at λ=1330.12nm

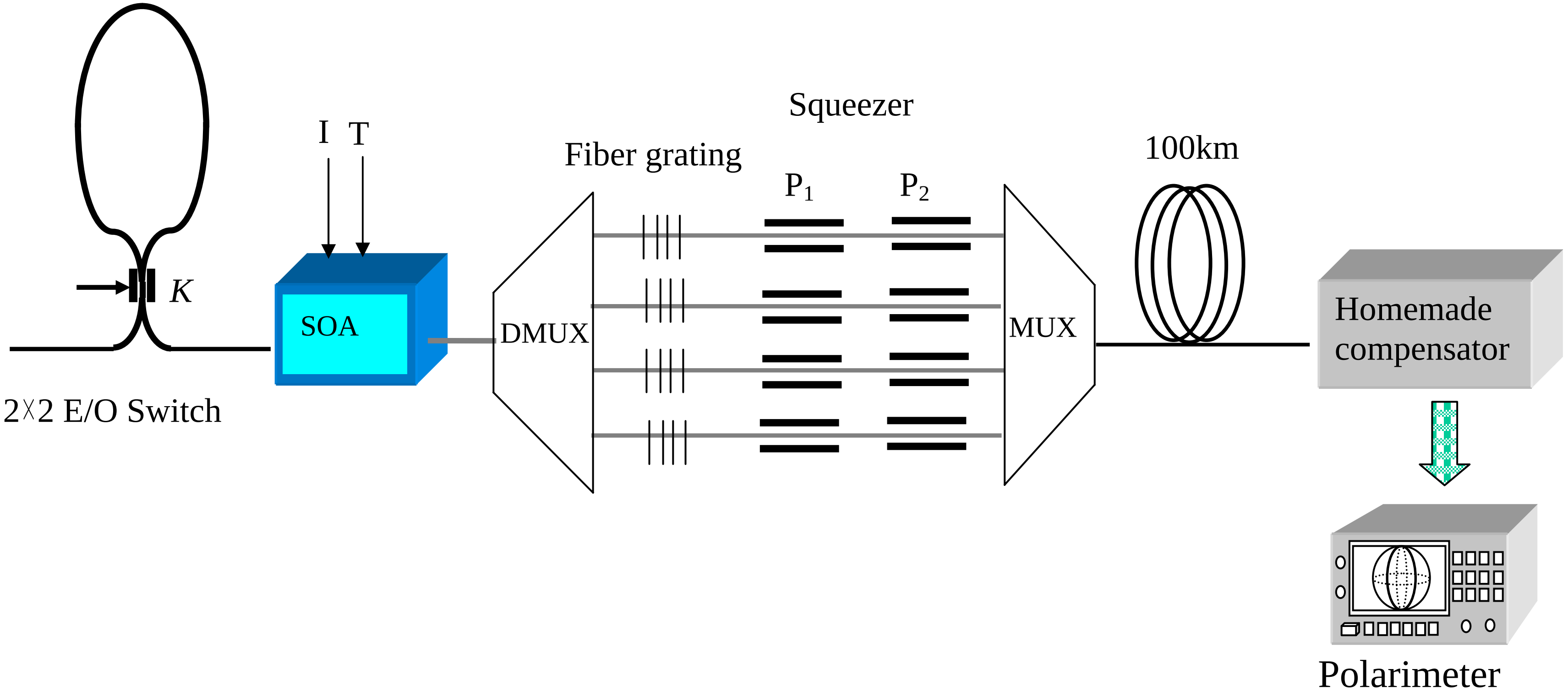


Fig. 4-7 The structure of WDM/PolSK system in the100Km transmission

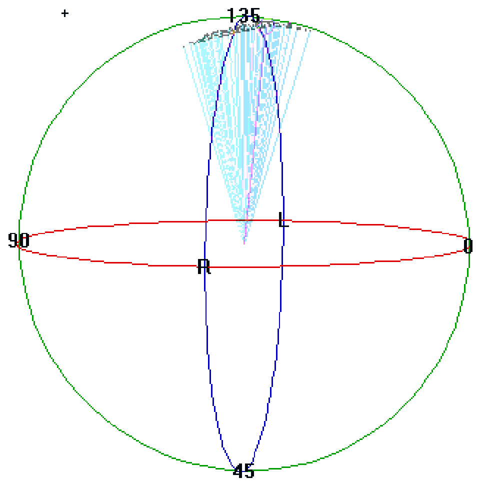


Fig. 4-8 (a) The polarization state without compensated at A position.

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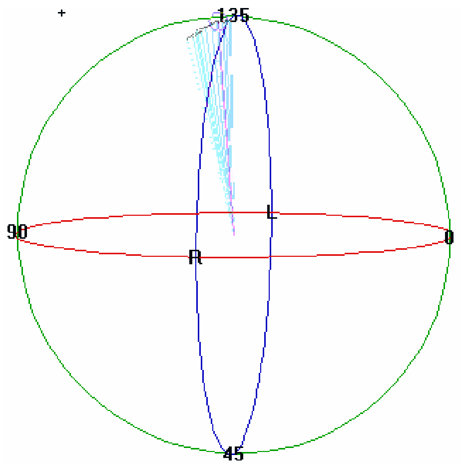

Fig. 4-8 (b) The polarization state with compensated at A position.

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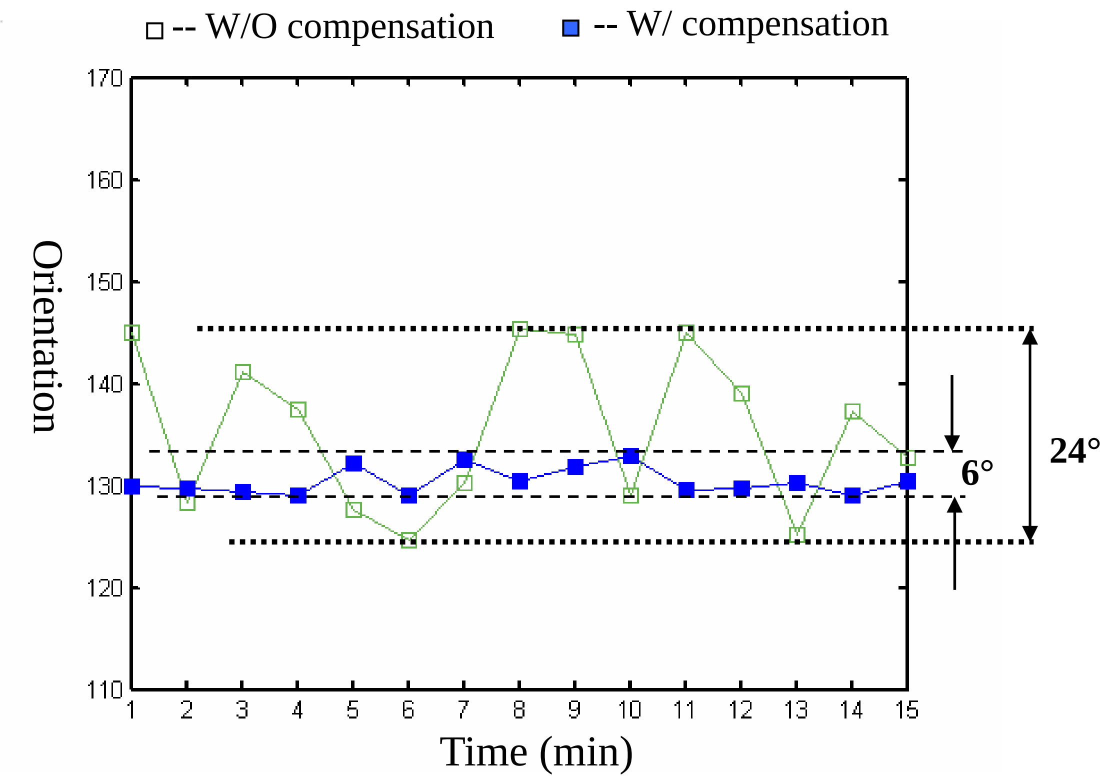

Fig. 4-9 The variation of orientation state with/without compensated at A position.

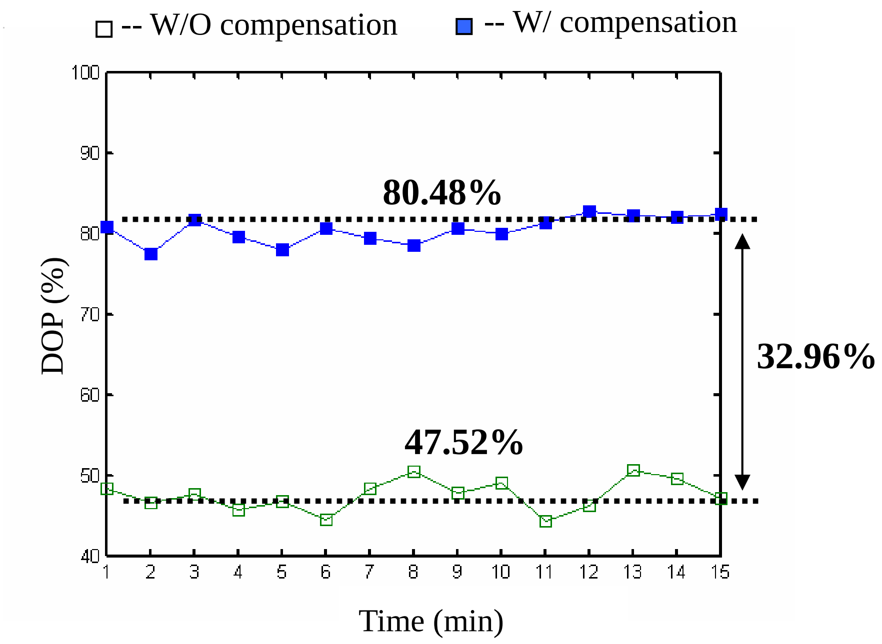

Fig. 4-10 The stable of DOP with/without turn on the homemade compensator at A position.

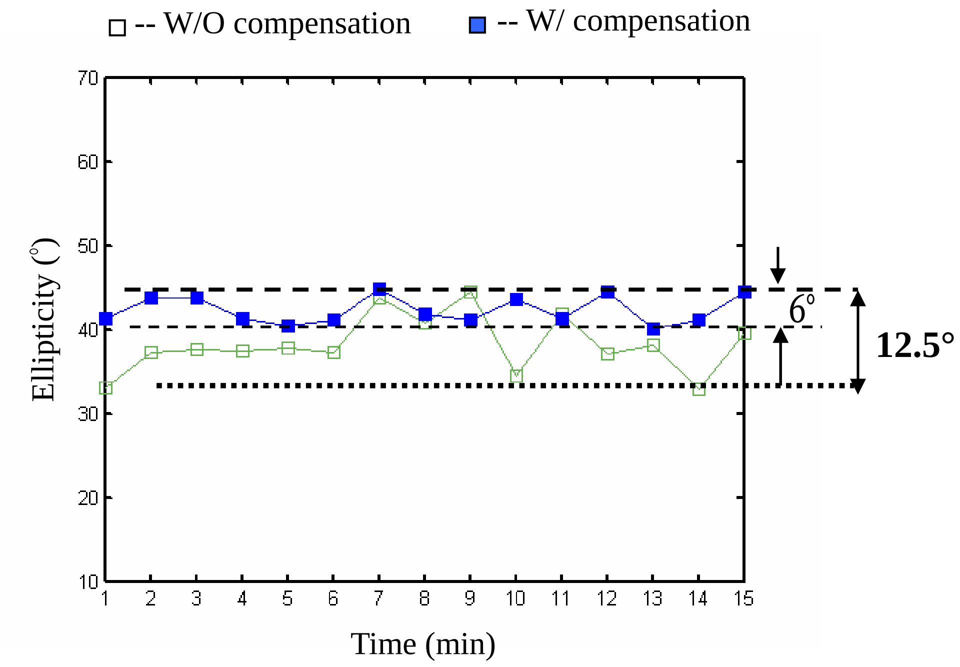

Fig. 4-11 The stability of ellipticity with/without turn on the homemade compensator at A position.

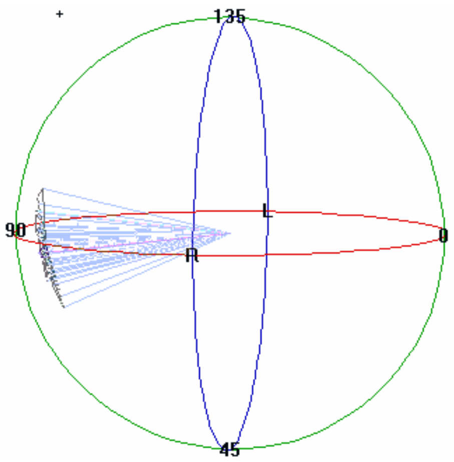

Fig. 4-12 (a) The polarization state without compensated at B position.

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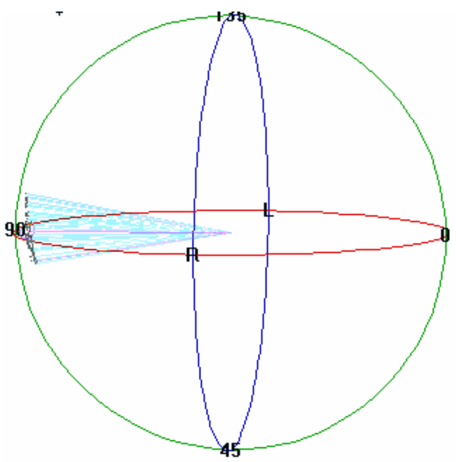

Fig. 4-12 (b) The polarization state with compensated at B position.

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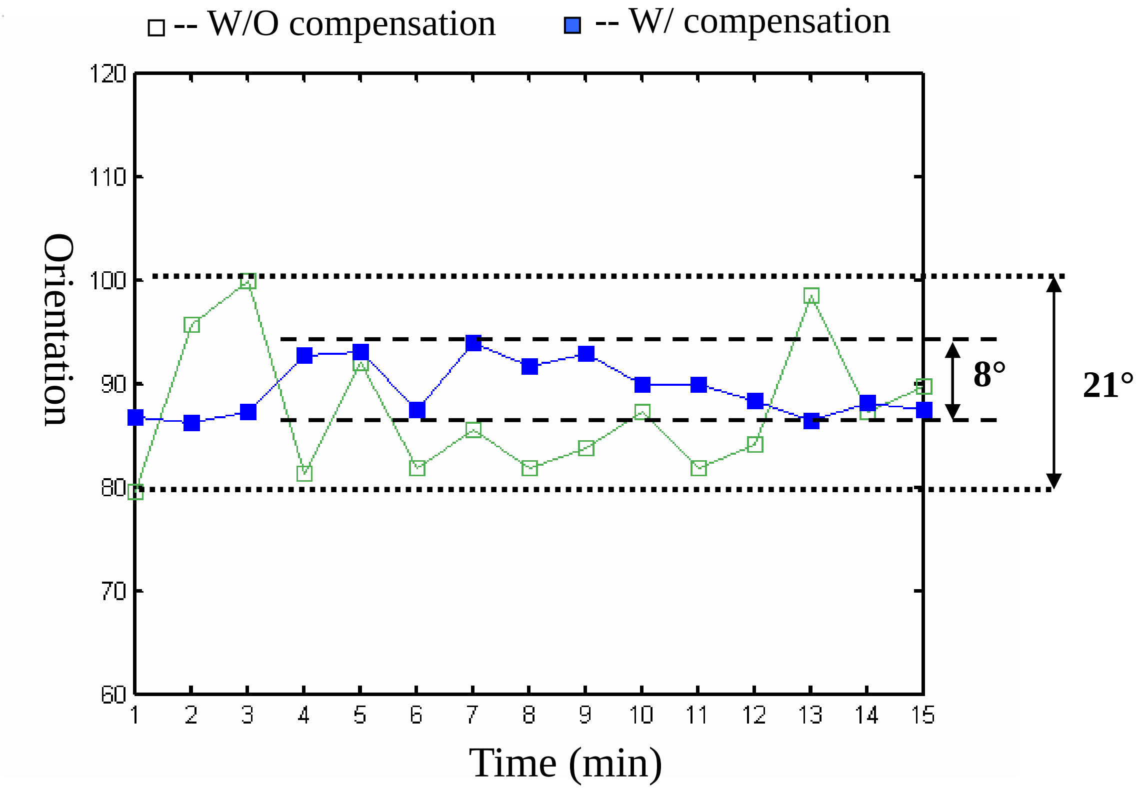

Fig. 4-13 The variation of orientation state with/without compensated at B position.

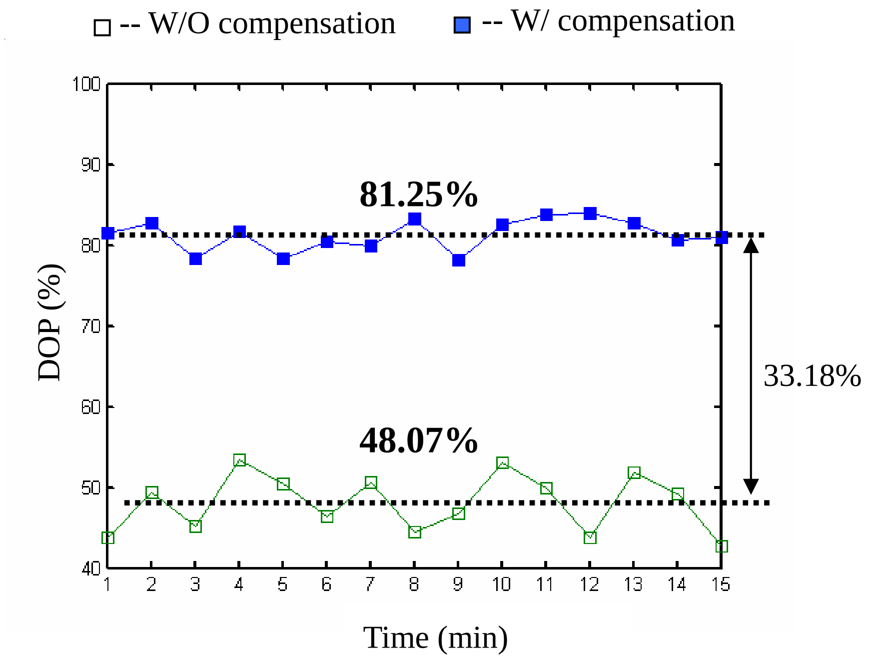

Fig. 4-14 The stable of DOP with/without turn on the homemade compensator at B position.

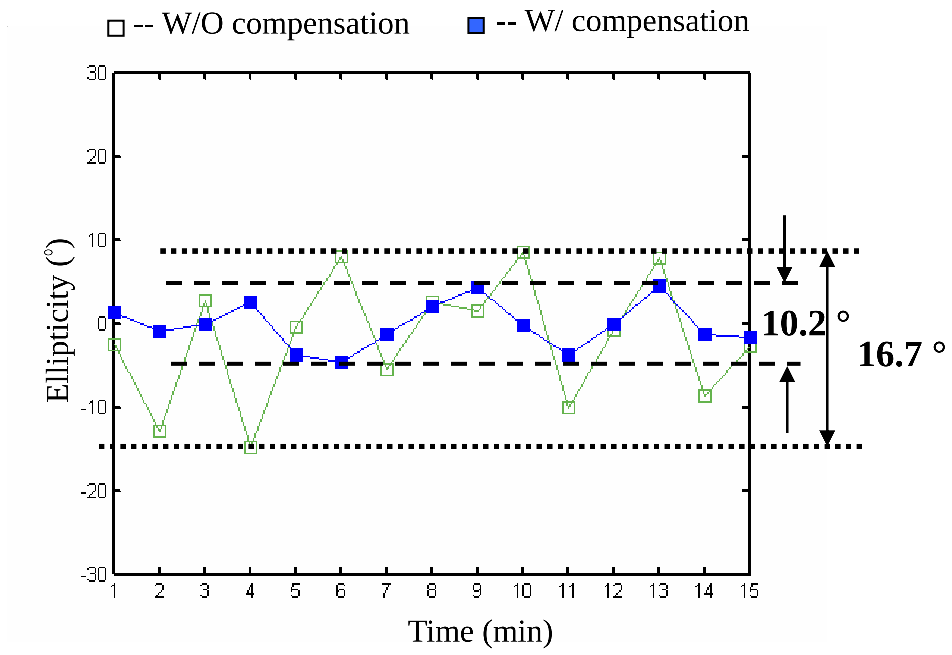

Fig. 4-15 The stability of ellipticity with/without turn on the homemade compensator at B position.

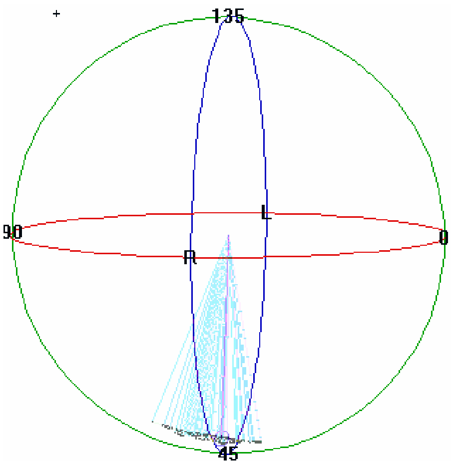

Fig. 4-16 (a) The polarization state without compensated at C position.

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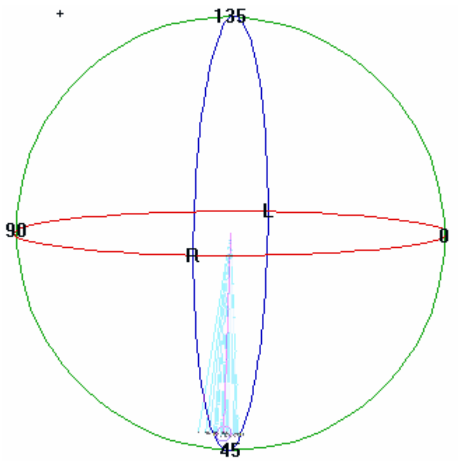

Fig. 4-16 (b) The polarization state with compensated at C position.

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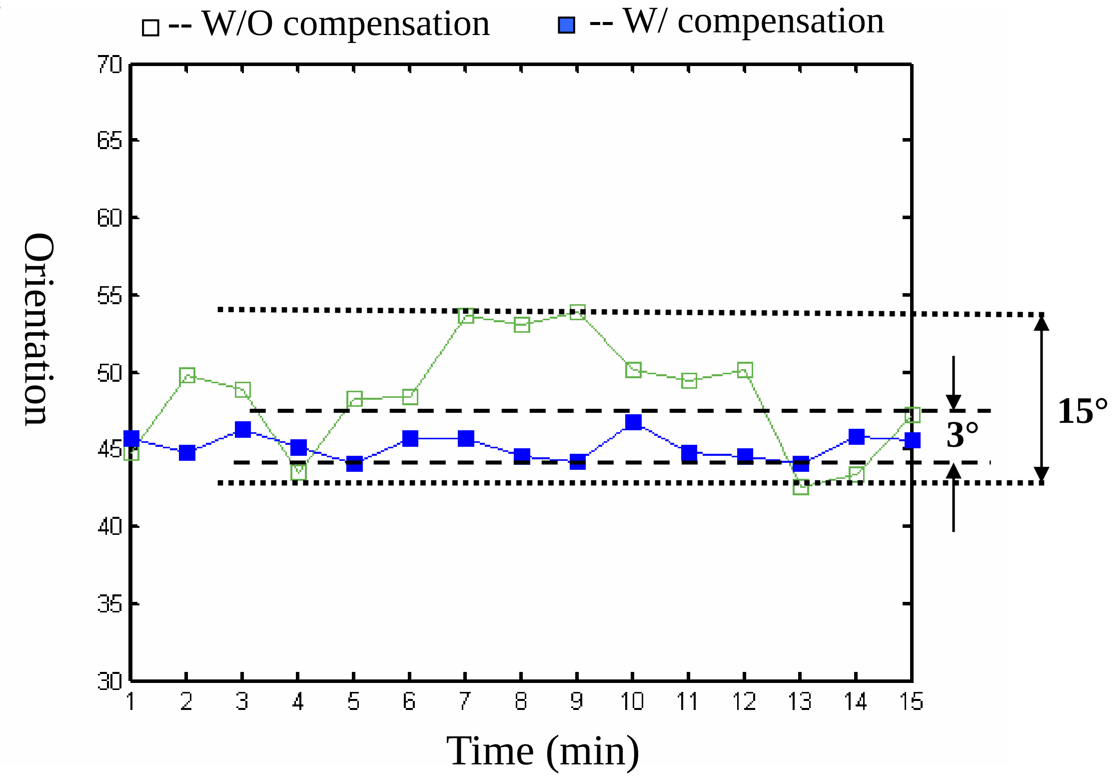

Fig. 4-17 The variation of orientation state with/without compensated at C position.

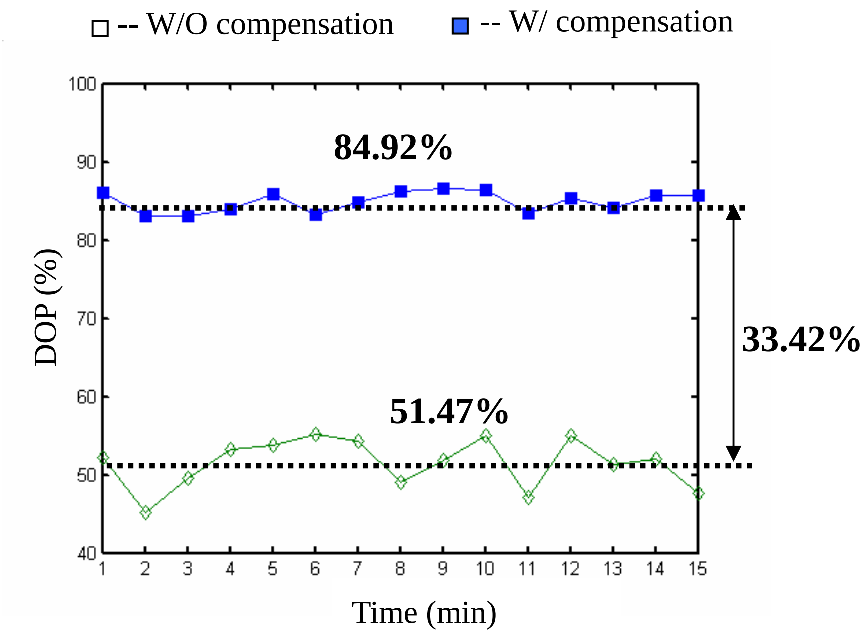

Fig. 4-18 The stable of DOP with/without turn on the homemade compensator at C position.

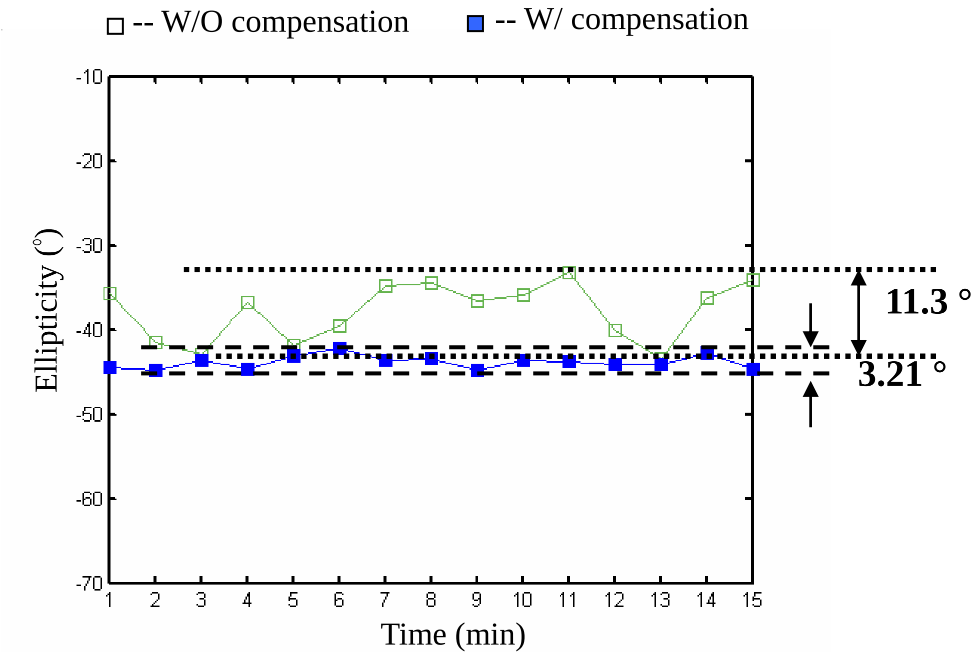

Fig. 4-19 The stability of ellipticity with/without turn on the homemade compensator at C position.

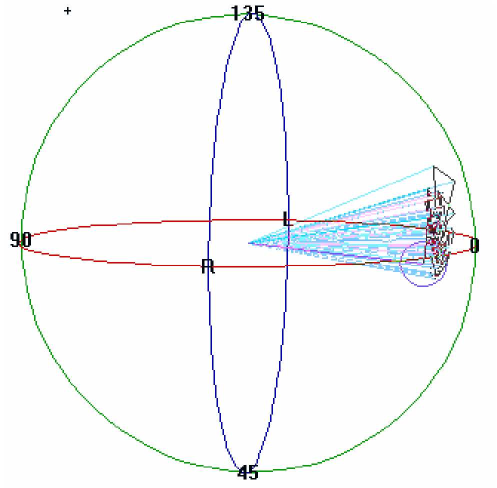

Fig. 4-20 (a) The polarization state without compensated at D position.

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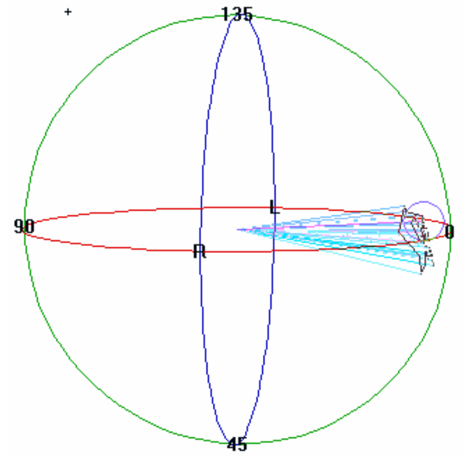

Fig. 4-20 (b) The polarization state with compensated at D position.

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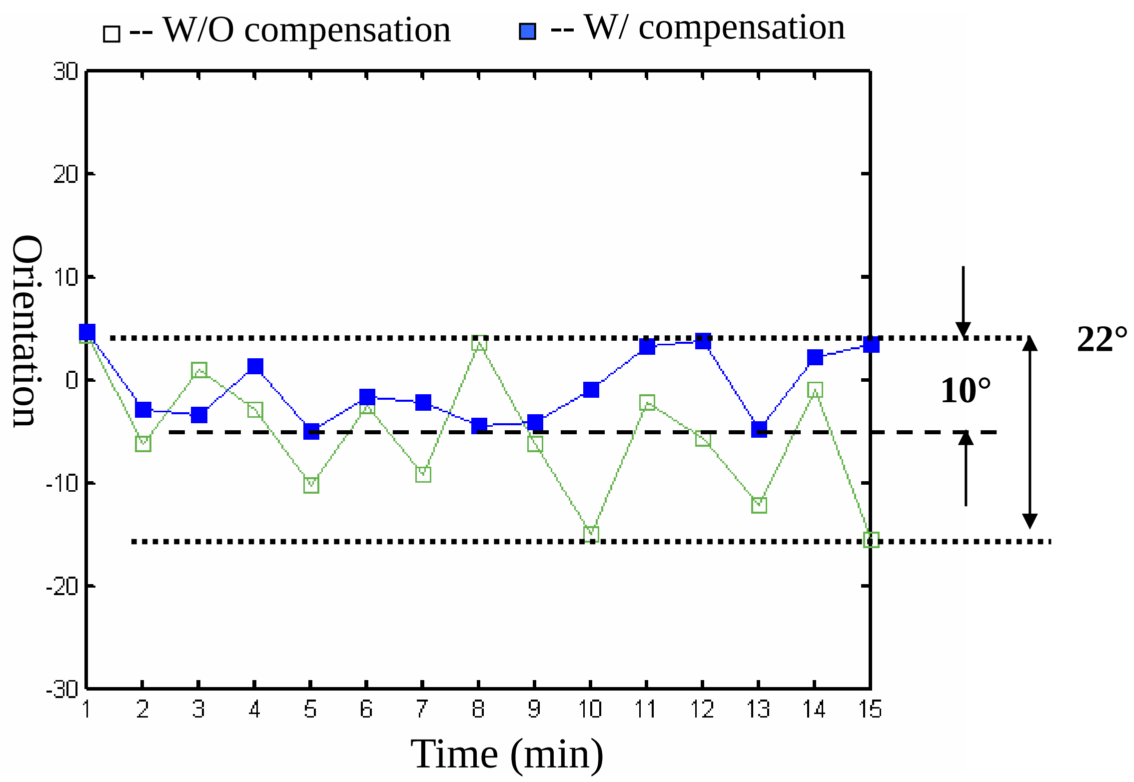

Fig. 4-21 The variation of orientation state with/without compensated at D position.

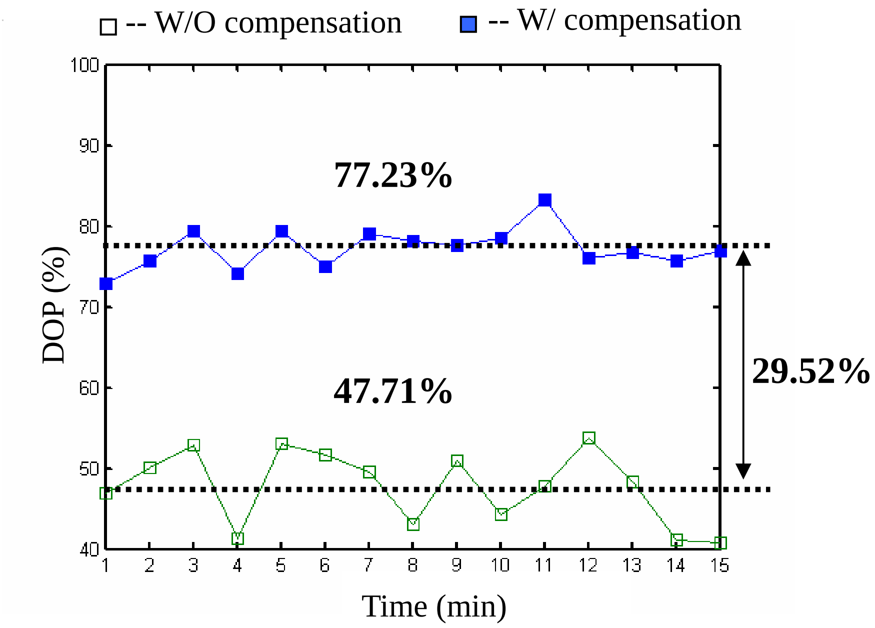

Fig. 4-22 The stable of DOP with/without turn on the homemade compensator at D position.

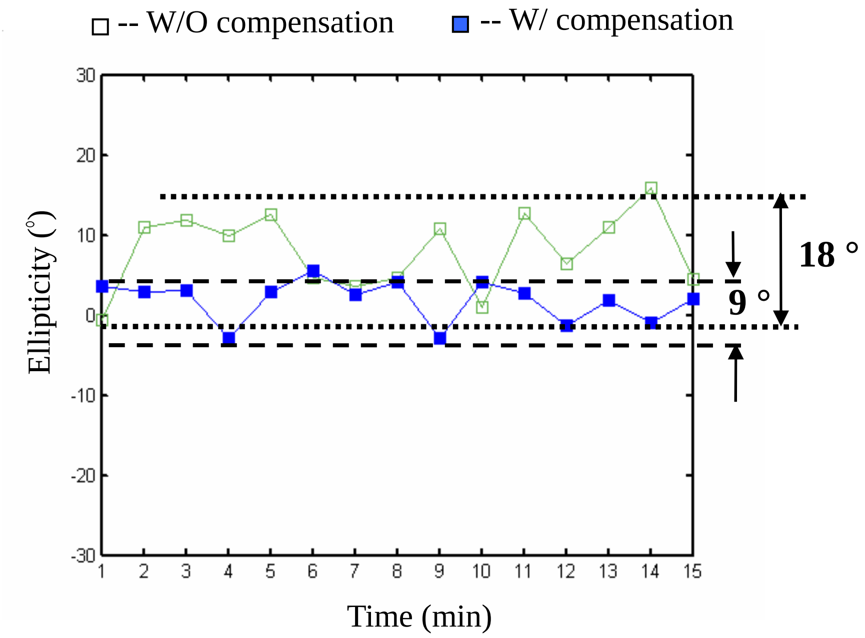

Fig. 4-23 The stability of ellipticity with/without turn on the homemade compensator at D position.

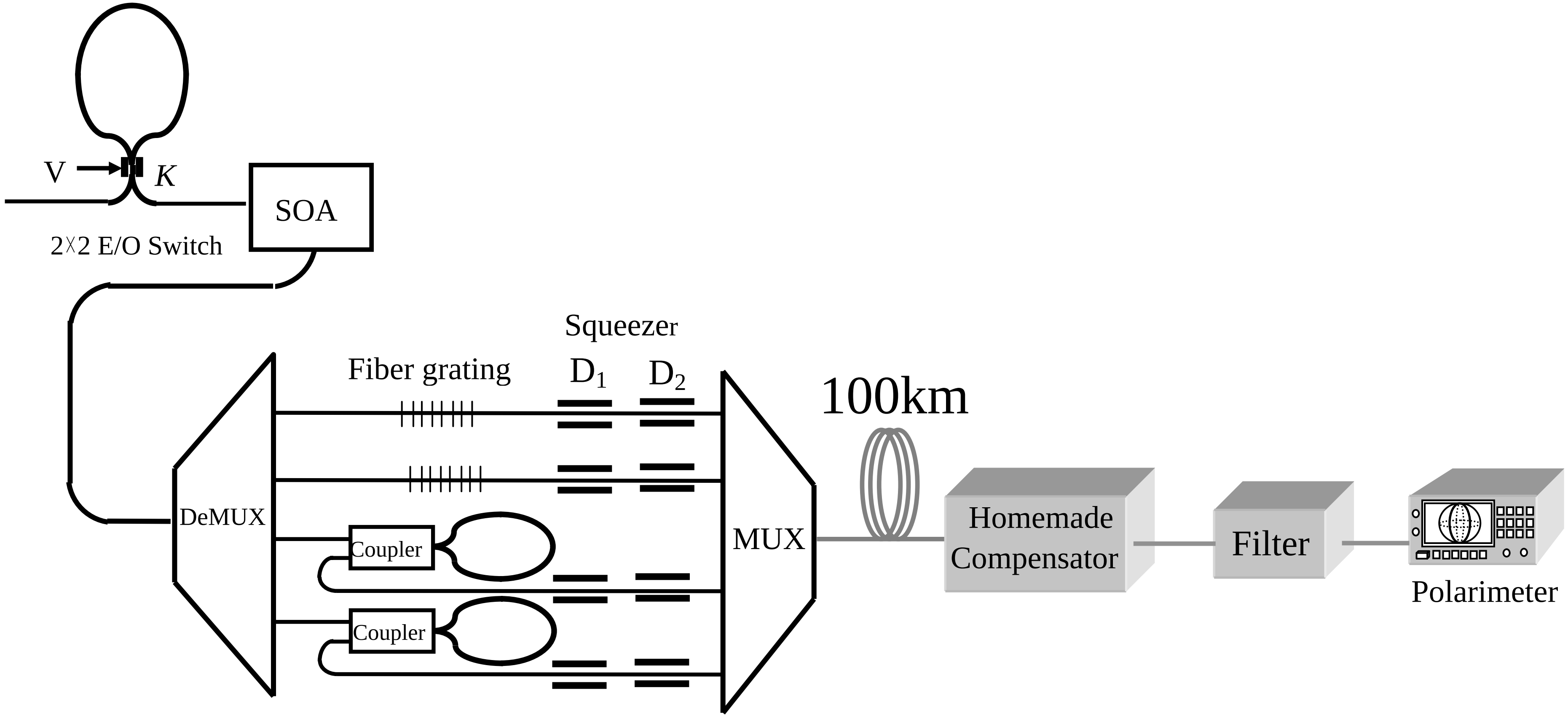

Fig. 4-24 The structure of WDM/PolSK system with the filter in the100Km transmission

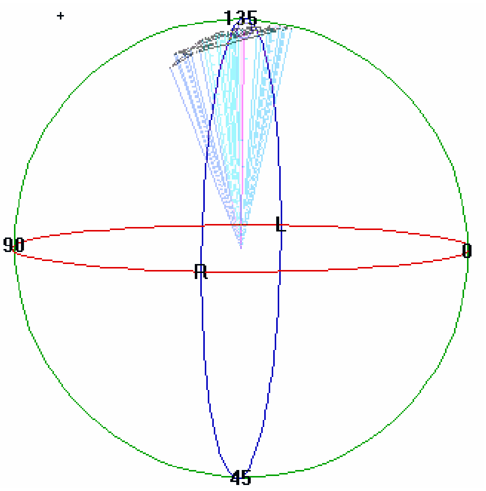

Fig. 4-25 (a) The polarization state without compensated in the Channel1 at A position

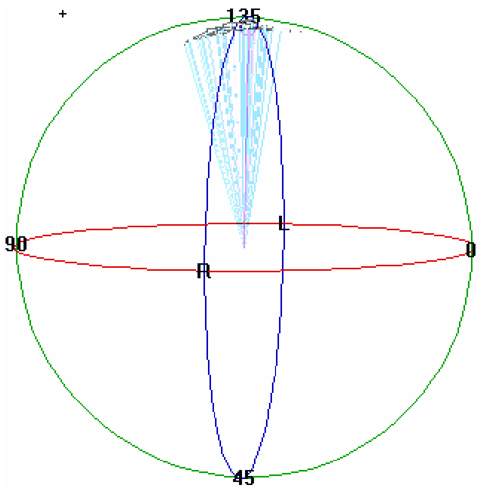

Fig. 4-25 (b) The polarization state with compensated in the Channel1 at A position

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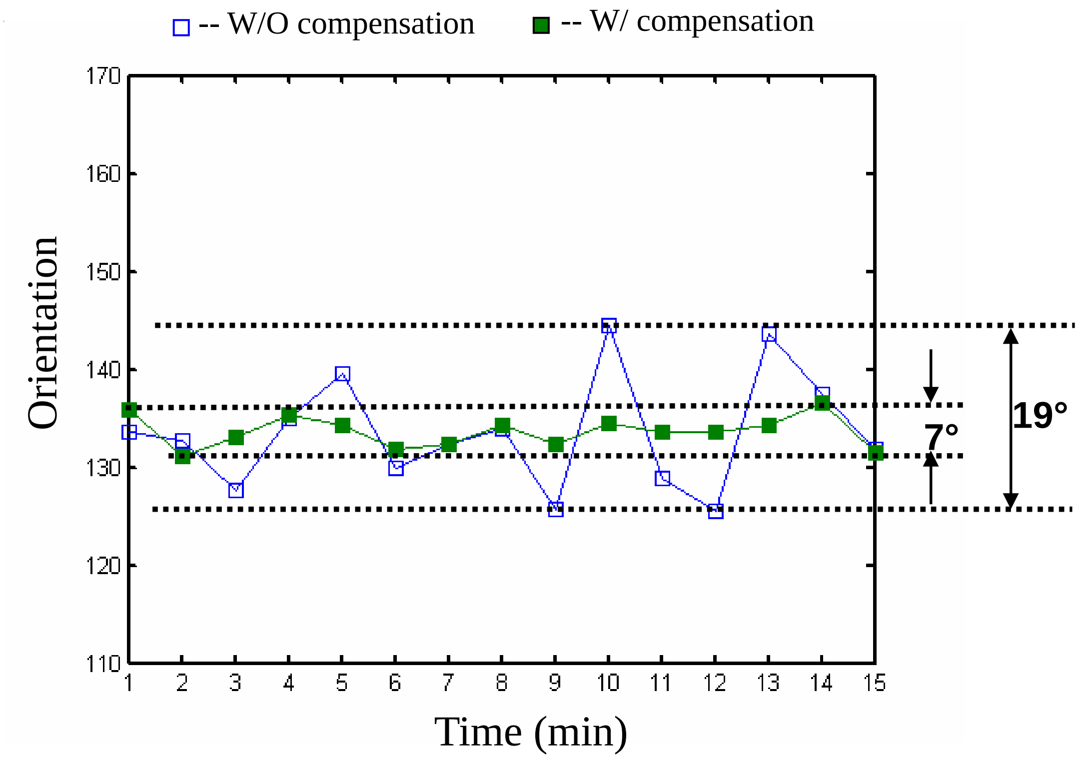

Fig. 4-26 The variation of orientation state with/without compensated in the Channel1 at A position.

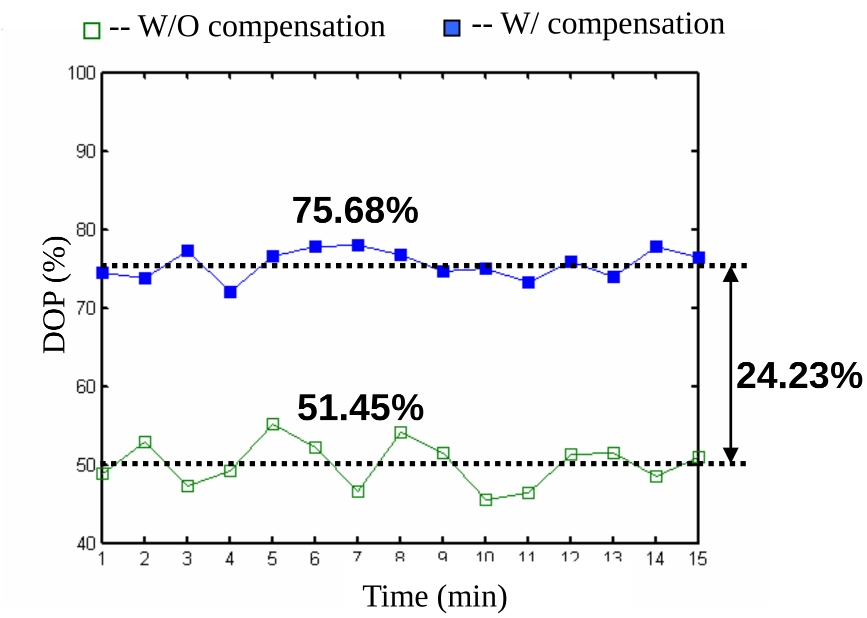

Fig. 4-27 The stable of DOP with/without turn on the homemade compensator in the channel1 at A position

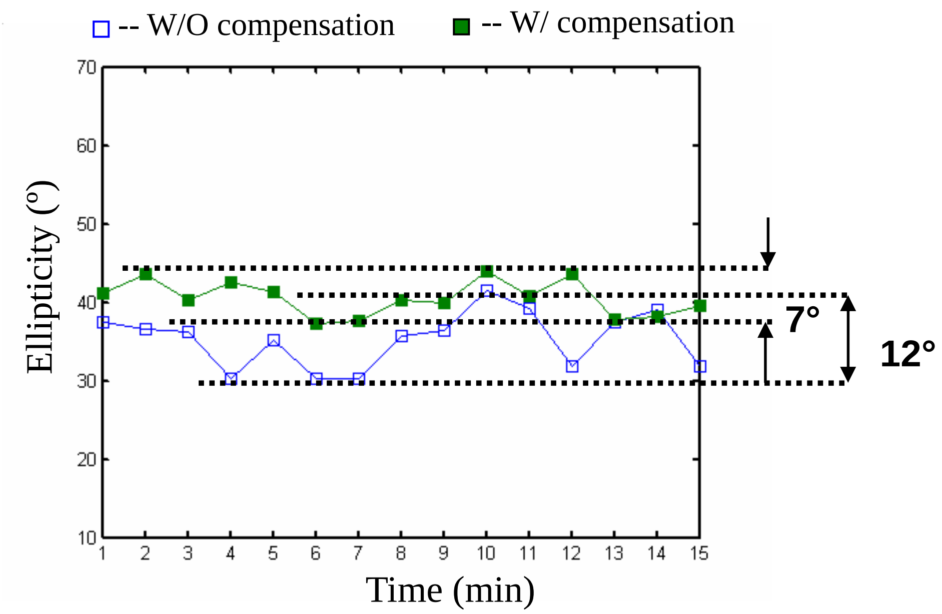

Fig. 4-28 The stability of ellipticity with/without turn on the homemade compensator in the channel1 at A position

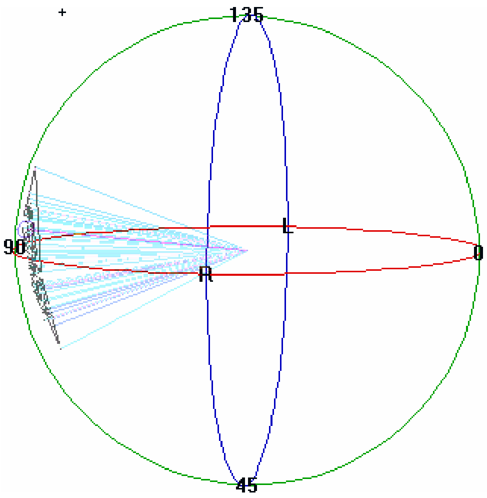

Fig. 4-29 (a) The polarization state without compensated in the Channel1 at B position

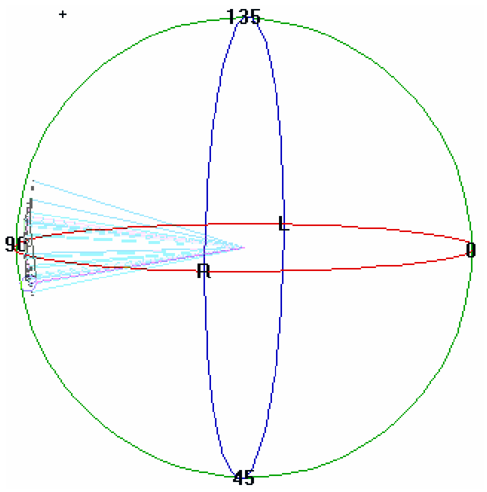

Fig. 4-29 (b) The polarization state with compensated in the Channel1 at B position

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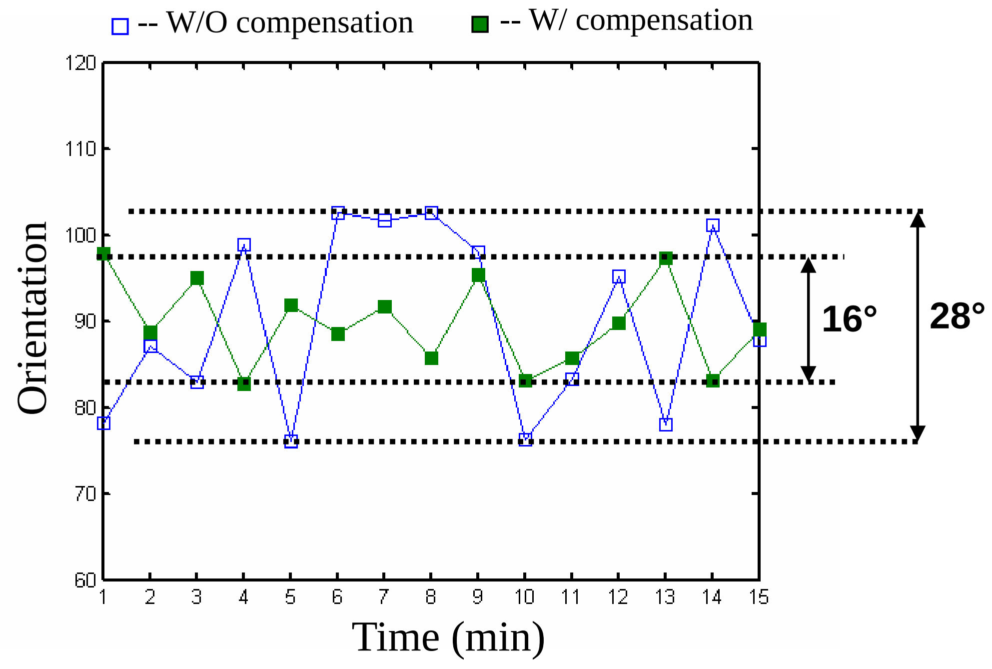

Fig. 4-30 The variation of orientation state with/without compensated in the Channel1 at B position

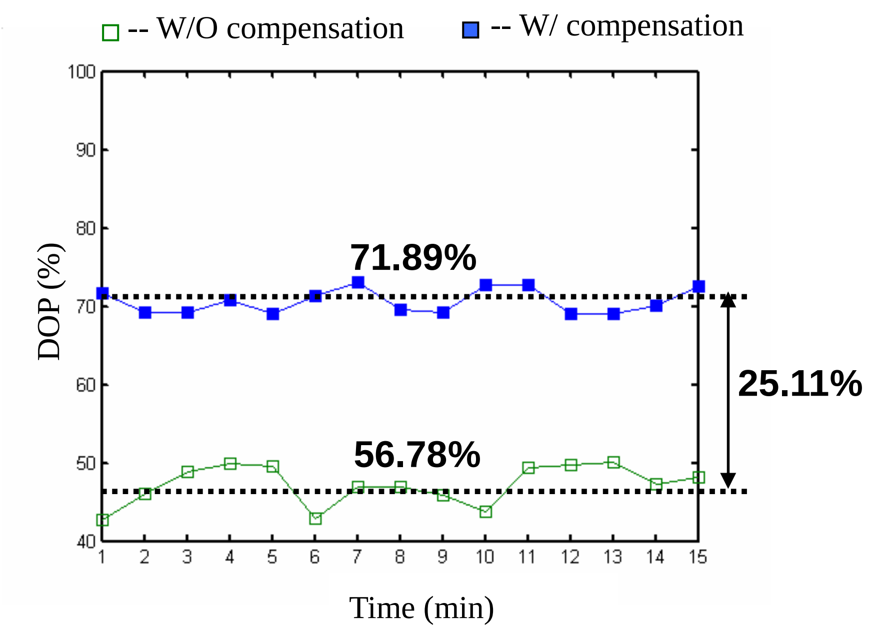

Fig. 4-31 The stable of DOP with/without turn on the homemade compensator in the channel1 at B position

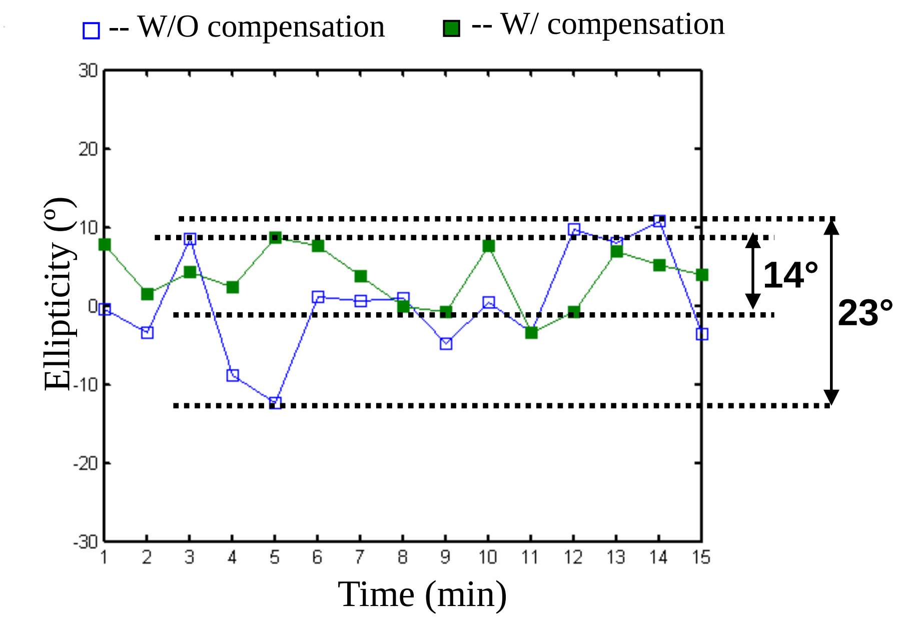

Fig. 4-32 The stability of ellipticity with/without turn on the homemade compensator in the channel1 at B position

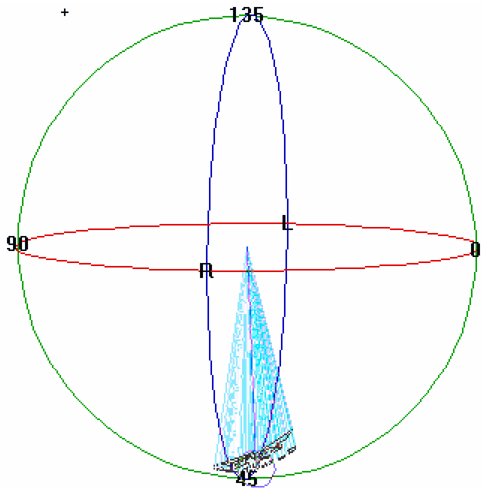

Fig. 4-33 (a) The polarization state without compensated in the Channel1 at C position

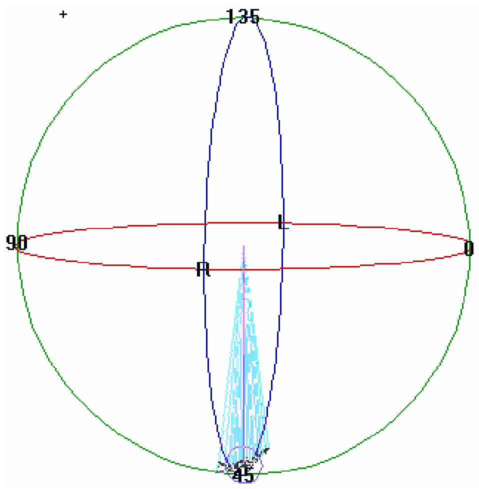

Fig. 4-33 (b) The polarization state with compensated in the Channel1 at C position

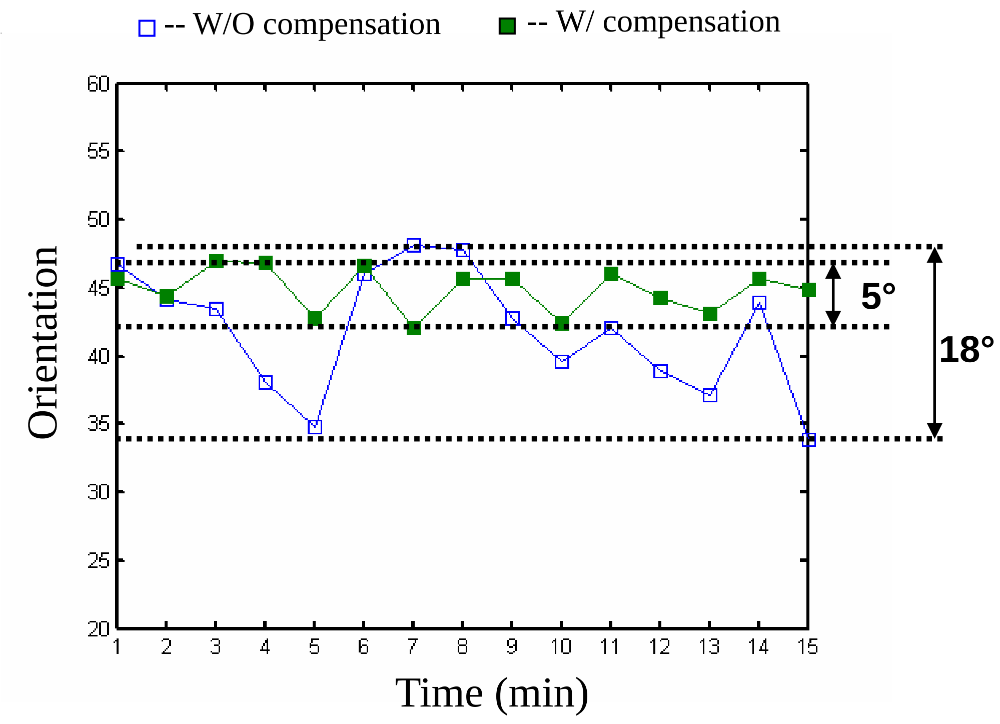

Fig. 4-34 The variation of orientation state with/without compensated in the Channel1 at C position

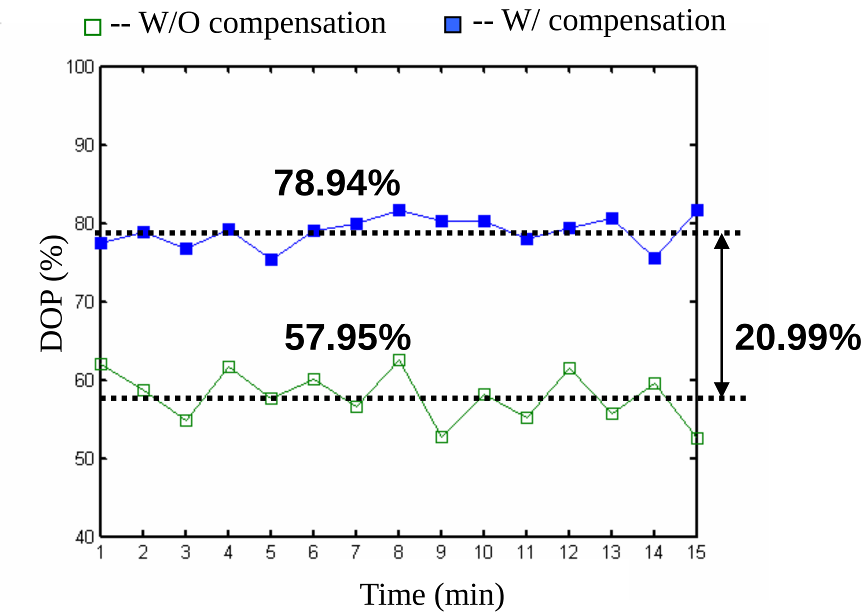

Fig. 4-35 The stable of DOP with/without turn on the homemade compensator in the channel1 at C position

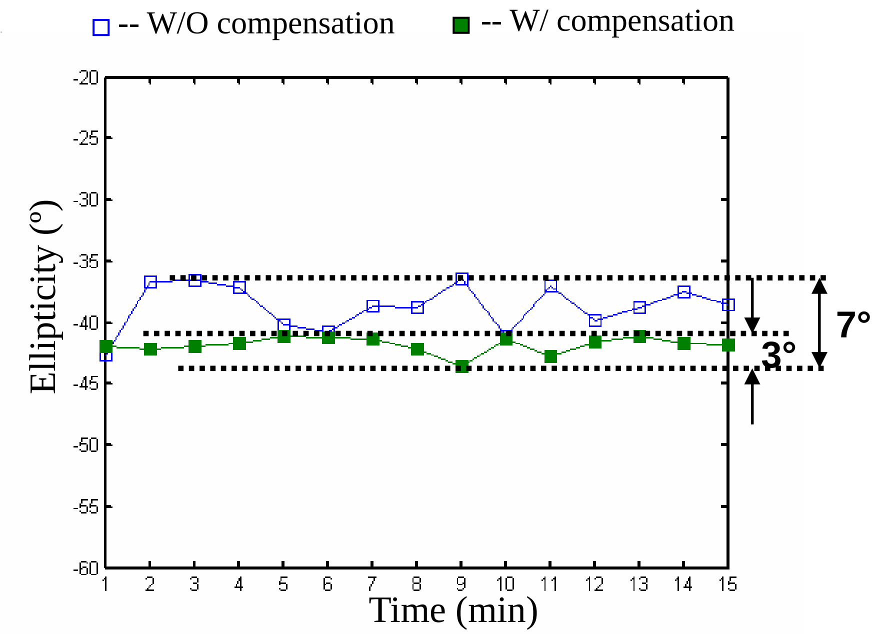

Fig. 4-36 The stability of ellipticity with/without turn on the homemade compensator in the channel1 at C position

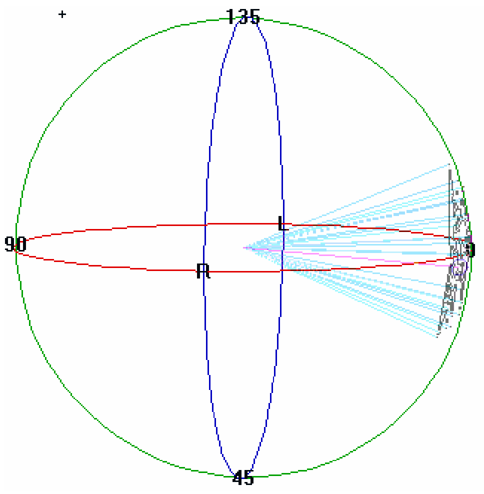

Fig. 4-37 (a) The polarization state without compensated in the Channel1 at D position

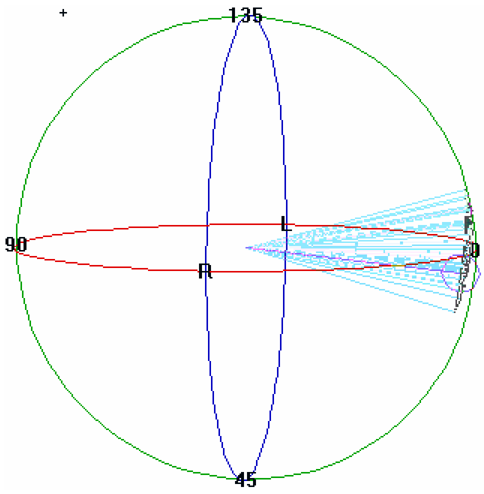

Fig. 4-37 (b) The polarization state with compensated in the Channel1 at D position

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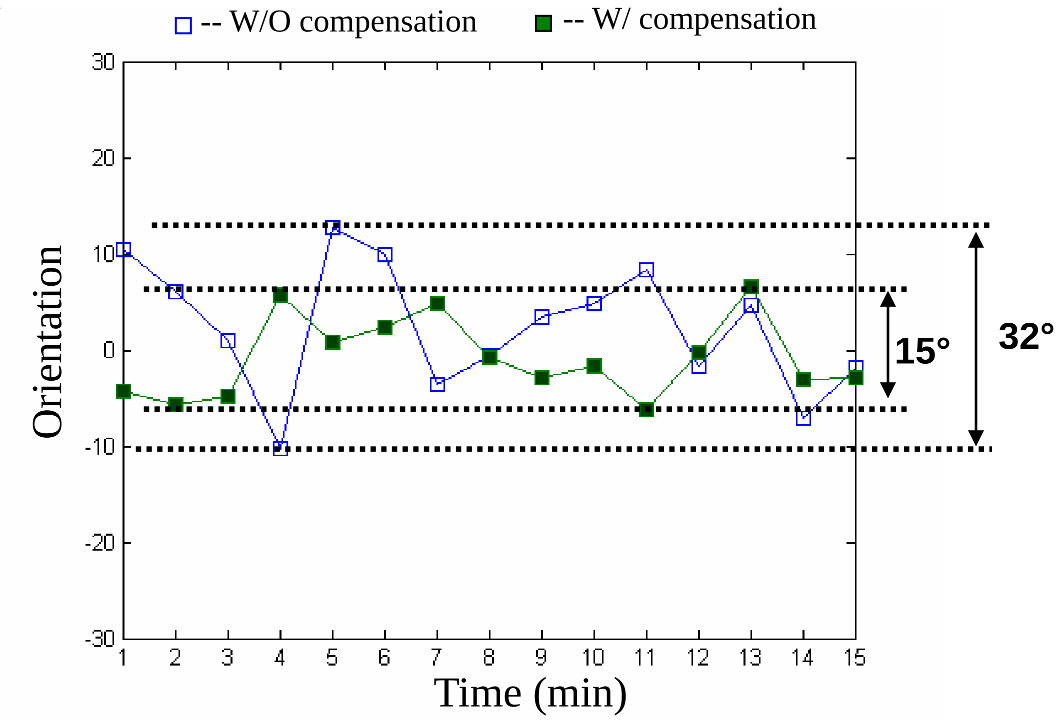

Fig. 4-38 The variation of orientation state with/without compensated in the Channel1 at D position

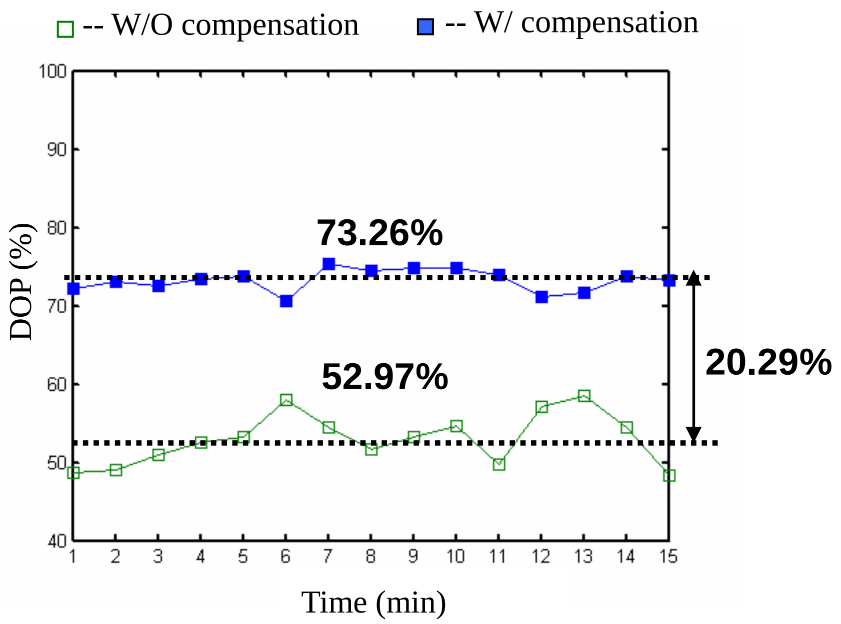

Fig. 4-39 The stable of DOP with/without turn on the homemade compensator in the channel1 at D position

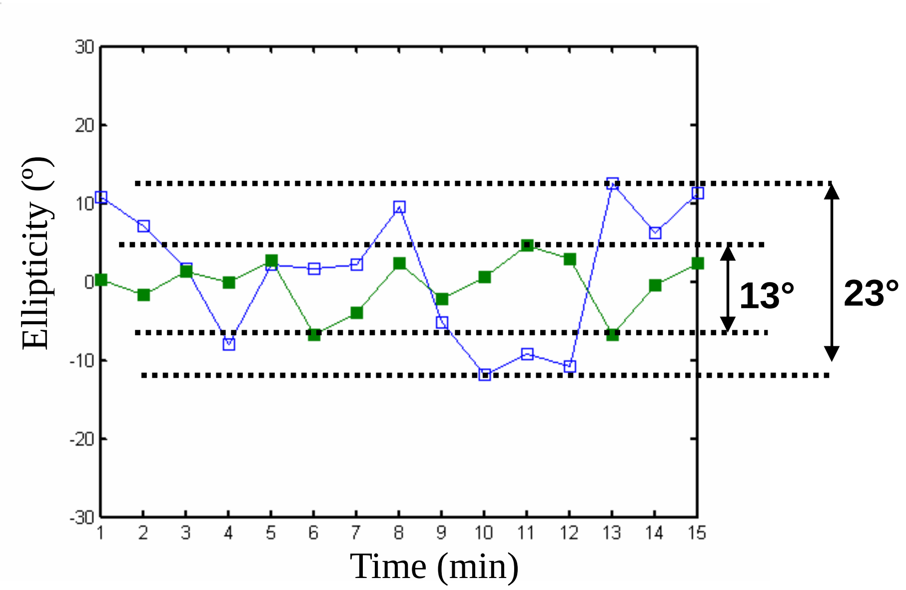

Fig. 4-40 The stability of ellipticity with/without turn on the homemade compensator in the channel1 at D position