**I J C T A**, 9(8), 2016, pp. 3465-3473

# Four Wave Mixing Technique Based Chromatic Dispersion Monitoring Using Optisystem Simulation

**T. Shanthi Priya* and I. Muthumani**

**ABSTRACT**

In this paper, the chromatic dispersion [CD] monitoring by a differential phase shift method using Kerr phase interrogator has been demonstrated. By exploiting the non-linear Kerr effect induced from single mode fiber which results in the generation of sidebands in the optical spectra, the proposed Kerr phase interrogator translates the phase shift between thesetwo sinusoidally modulated optical signals into sinusoidal power variation of these sidebands. This can be easily detected using basic opto-electronic devices.Thus, the simulated design of this paper analyses the power variations of first order sideband as a result of non-linear interactions and also can explain the CD impact of kerr medium. The Kerr phase interrogator based technique for measuring phase shift is a promising approach for monitoring and sensing applications. The simulated model of the proposed system has been implemented by using Optisystem software and verified the results obtained from various discussions.

***Keywords:*** Chromatic dispersion (CD), Kerr phase interrogator, Mach Zehndermodulator, single mode fiber (SMF), dispersion shifted fiber(DSF), highly nonlinear fiber (HNLF)

## 1. INTRODUCTION

Chromatic dispersion is one of the major limitations in optical transmission links due to the imposed maximum optical fiber length for a considered bit rate. So various chromatic dispersion monitoring schemes are evolved. An effective residual CD monitoring scheme is very important for such high speed transmission systems[1, 2]. Some other techniques are based on monitoring of the magnitude of AM pilot tones [3, 4], phase shift detection [5], nonlinear effects in highly nonlinear fiber [6], among other. CD monitoring scheme was proposed by comparing the phase ofrecovered clock of received I and Q channel signals of DQPSK modulated data [7]. No additional monitoring signals are required but it needs clock recovery and high speed phase comparator which results in increased system complexity and cost.Inorder to avoid clock recovery, asynchronous sampling method such as amplitude histogram evaluation [8] was used and thus has inherently low cost. However, since different impairments can cause similar degradation in amplitudehistogram, it is difficult to distinguish them. Thus, the delay tap asynchronous sampling has been proposed [9, 10]. Another monitoring scheme was proposed by using various modulation formats such as on-off keying (OOK), differential phase shift keying (DPSK), differential quadrature phase shift keying (DQPSK) at different data rates [11]. Recently demonstrated a kerr phase interrogator that measures phase shift between two sinusoidal signals carried by the same laser wavelength using phasemodulation induced by kerr effect [12-14]. In this paper, the proposed scheme accomplishes CD monitoring by analyzingthe impact of CD of kerr medium on the nonlinear interaction between two sinusoidally modulated optical signals using theory of FWM andthe impact of CD on the generation of first-order sideband.

---

* Department of Electronics and Communication, Alagappa Chettiar College of Engineering and Technology, Karaikudi–630003, India, *Email: shanthipriya5ece@gmail.com*

## 2. DESIGN

In differential phase shift method, two continuous wave lasers are used carrying two different wavelengths at $\lambda_1$ and $\lambda_2$. Then it is combined using power combiner. The power combined signal and RF signal from sinusoidal signal generator are modulated by Mach Zehndermodulator. Aftermodulation, it generates a double sideband suppressed carrier signalwhich is in a kerr phase interrogator in order to obtain the frequency signals.

**Table 1**
**Laser Specifications**

| | |
|---|---|
| $\lambda_1$ | 1550.05 nm |
| $\lambda_2$ | 1550.91m |

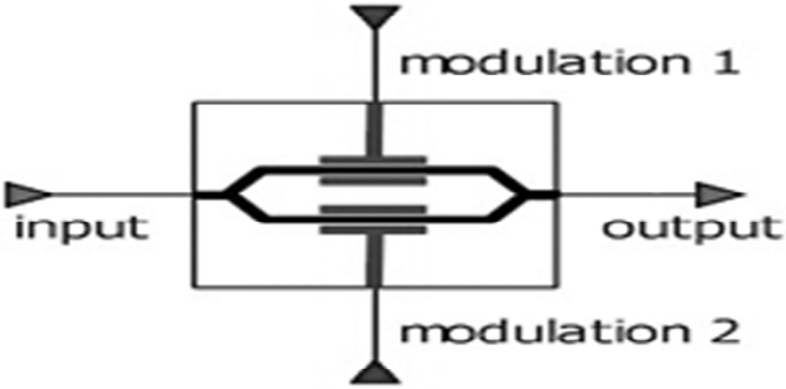

**Figure 1: Mach Zehnder Modulator**

### 2.1. Double sideband suppressed carrier signal generation

A dual drive mach zehnder modulator is used for the generation of DSB-SC signal and this configuration as shown in fig. 1. The electric field oscillating at optical frequency $v_0$ is split into $E_1$ and $E_2$ respectively which propagate in two arms of the modulator. A sinusoidal electrical signal with magnitude and oscillation frequency is applied to the modulator by a sine generator to obtain the sinusoidal modulation in the phase shift between two light waves in two arms of mach zehnder modulator.This sinusoidal phase modulation leads to distinct sidebands with frequency interval of $2 f_m$ in the output optical spectrum of the modulator. The bias voltage is applied to the mach zehnder modulator to suppress the even order generated sidebands in the output spectrum of the modulator.

The magnitude of appliedsinusoidal electrical signal is chosen as 1v to ensure that only two first order generated sidebands dominate in the output optical spectrum of modulator. The existence of two dominating sidebands separated by $f_s = 2 f_m$ in the optical spectrum leads to the sinusoidal output power at frequency $f_s$.

### 2.2. Kerr phase interrogator setup

The modulated signals then propagate through a single mode fiber, that induces an accumulated CD equivalent to $D_c*L = t_d/\Delta\lambda_1$, where $D_c$ is the CD parameter $L$ is the propagation distance, $t_d = t_2 - t_1$ is the group delay difference of two sinusoidal signals induced by single mode fiber with $t_j$ being the group-delay accumulated by the sinusoidal signal carried by laser carrier at $\lambda_j$ and $\Delta\lambda_1 = \lambda_2 - \lambda_1$ is the laser carrier separation. The output of single mode fiber pass through kerr phase interrogator setup. The kerr phase interrogator setup is shown in fig. 2.

Two sinusoidally modulated optical signals at $f_s$ and the optical spectrum of eachsinusoidally modulated optical signal consists of twodistinct peaks.Theparallel and perpendicular components of the sinusoidally

**Table 2**
**Sine Generator Specifications**

| | |
|---|---|
| Frequency | 9 GHZ |
| Amplitude | 1 |

**Table 3**
**Dual Drive Mach Zehnder Modulator Specifications**

| | |
|---|---|
| Splitting ratio | 1.1 |
| Bias voltage 1 | -1.9 v |
| Bias voltage 2 | -1.9 v |

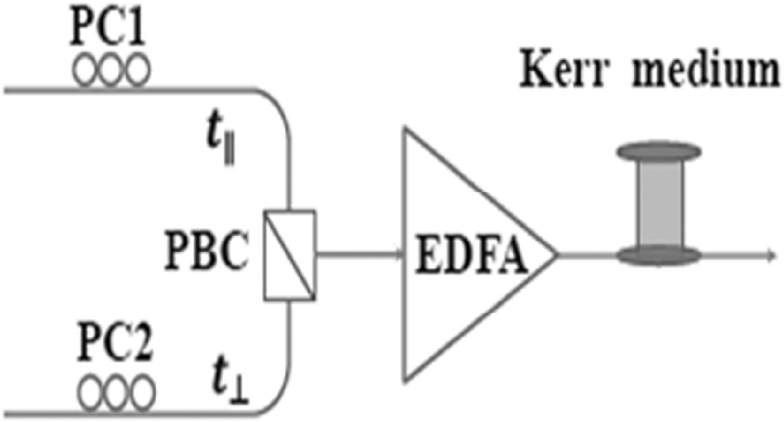

**Figure 2: Schematic representation of kerr phase interrogator**

modulated optical signals are respectively combined by a polarization beam combiner (PBC) to obtain two orthogonally polarized SMOSs.Two polarization controllers $PC_1$ and $PC_2$, maximize and equalize the powers at the output of PBC.The combined signal at the output of PBC is amplified using an erbium-doped fiber amplifier and then is launched into a kerr medium comprised of dispersion-shifted fiber with a $L_{kerr.}$

## 3. SIMULATION

Optisystem simulation software is used to analyse and demonstrate the proposed structure.The system setup for the chromatic dispersion monitoring using kerr phase interrogator with optisystem employed to demonstrate sinusoidal variation of power in the case of sinusoidal signals carried by different carrier wavelengths is as shown in fig. 3. The operating wavelengths of laser are set to $\lambda_1 = 1550.05$ nm and $\lambda_2 = 1550.91$ nm arecombined and the output of optical spectra of power combiner as shown in fig. 4.

**Table 4**
**Single Mode Fiber Specifications**

| | |
|---|---|
| Length | 0.1 km (sweep) |
| Dispersion | 16 ps/nm/km |

**Table 5**
**Dispersion Shifted Fiber Specifications**

| | |
|---|---|
| Reference wavelength | 1552 nm |
| Length | 20 km |
| Dispersion | 0.04 ps/nm/km |
| Dispersion slope | 0 ps/nm^2/k |

These input are amplitude modulated by dual drive machzehnder modulator and a sinusoidal electrical signal generator at a radio frequency (RF) $f_m$ at 9 GHz to obtain two sinusoidal optical signals with power oscillation frequency $fs = 2f_m$ as shown in fig 5. The modulated signals then propagate through a single mode fiber, that induces an accumulated CD equivalent to $D_c*L = t_d/\Delta\lambda_{1,}$ where $D_c$ isthe CD parameter, $L$ is the propagation distance, $t_d = t_2 - t_1$ is the group delay difference of two sinusoidal signals induced by single mode fiber with $t_j$ being the group-delay caused by the sinusoidal signal carried by laser carrier at $\lambda_j$ and $\Delta\lambda_{1=}\lambda_2$-$\lambda_1$ is the laser carrier separation. The sinusoidal optical signals are separated using a fiber Bragg grating and acirculator and then recombined using a fiber-coupled polarization beam combiner to obtain two polarized sinusoidal opticalsignals.Two polarizationcontrollers PC1 and PC2 ensure the powers of the parallel and perpendicular components of the combined signal are maximum and equal. The combined signal is amplified by an EDFA and then launched into a kerr medium comprised of a dispersion shifted fiber (DSF) with length of 20 km, then the dispersion impact ofkerr medium on the sinusoidal variation of

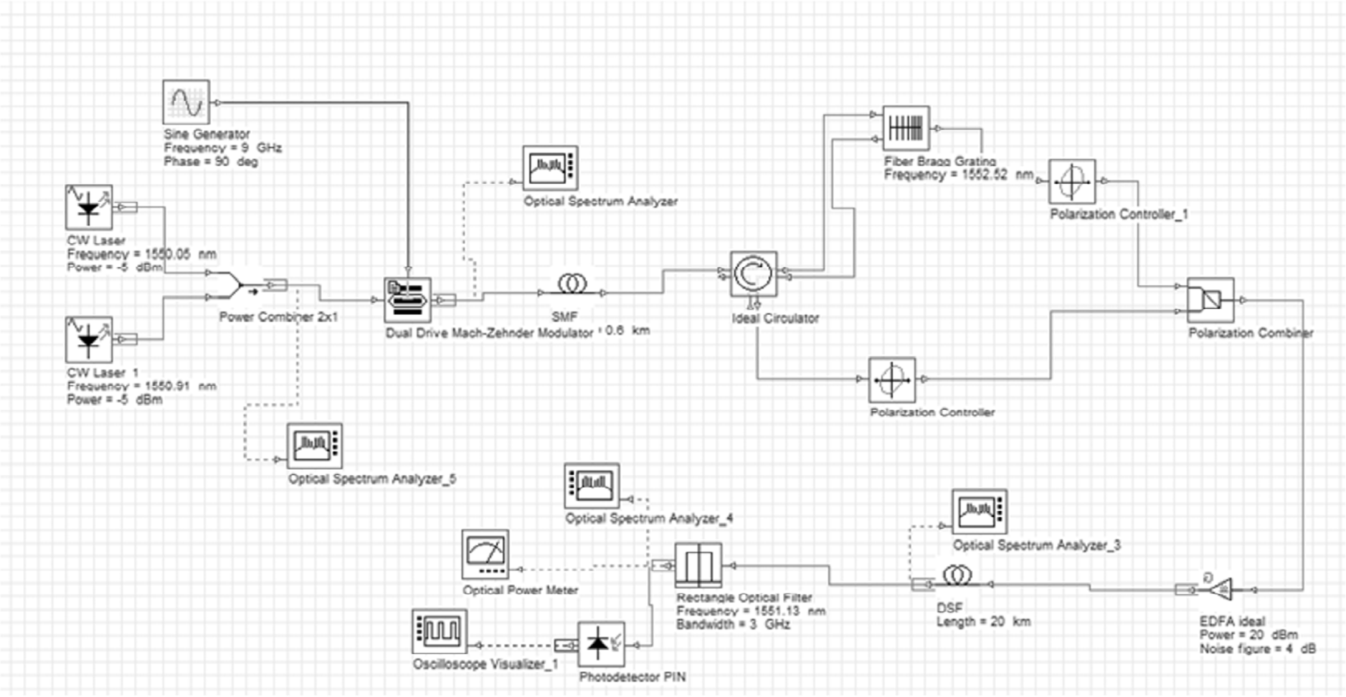

**Figure 3: Simulation setup of the chromatic dispersion monitoring based on a kerr phase interrogator**

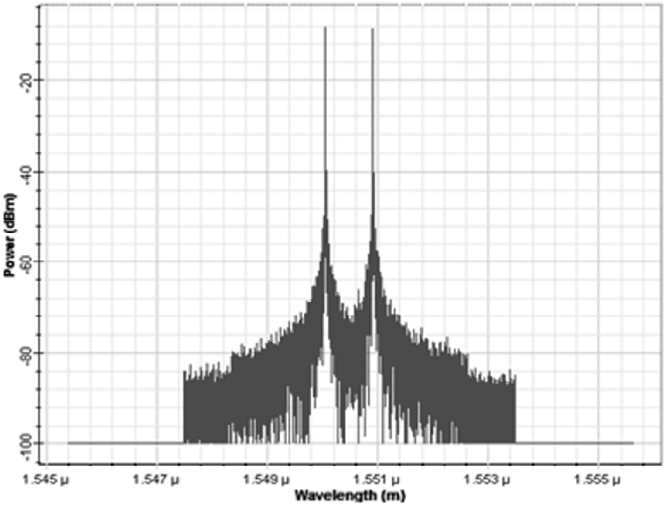

**Figure 4: Measured spectra at the output of the laser**

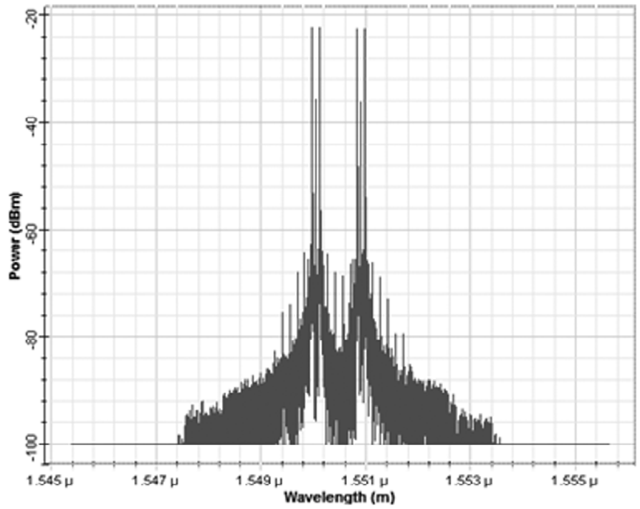

**Figure 5: Measured spectra at the output of the modulator**

power is neglected.The first order sideband generated in the kerr medium is extracted by a rectangle optical filter with 3db bandwidth of 3 GHz and a power meter used to measure power as length is varied in single mode fiber.

## 4. RESULTS AND DISCUSSIONS

The operating wavelengths of the lasers are set to $\lambda_1$ = 1550.05 nm and $\lambda_2$ = 1550.91 nm, and the modulation frequency is set to $f_m$ = 9 GHz. The accumulated CD is varied from 1.6 ps/nm to 9.6 ps/nm and the spectrum of the signal at the output of the Kerr medium is measured by an optical spectrum analyzer as shown in fig. 6.

### 4.1. Chromatic dispersion impact on the generationof first order sidebands

The first order sideband generated in the kerr medium is extracted by a rectangle optical filter with 3db bandwidth of 3 GHzand a power meter used to measure power as accumulated CD is varied as shown in fig. 7

The sinusoidal dependence is foundin power of first order sideband P1 versus phase shift between the optical signals. Hence a kerr phase interrogator can measure parameters that change the phase shift between two signals by measurement of P1 and are a promising approach for monitoring and sensing applications.Because chromatic dispersion (CD) affects theefficiency of nonlinear process.CD of the kerr medium that is used in a kerr phase interrogator has impact on the generation of first order sideband leading to deviation from the expected phase shift measurement.This proposed model provide insight into the impact of CD on the operation of the kerr phase interrogator as a sensing and signal processing device and simplify the design of the kerr phase interrogator to achieve optimal performance.Thus this model can be obtained by the utilization of the theory of four wave mixing (FWM) to study the nonlinear effect between two sinusoidal signals.

### 4.2. To determine the normalized power

The normalized power $P1/P1^{max}$ is obtained as the accumulated CD is varied from1.6 ps/nm to 9.6 ps/nm.The normalized power calculated, showing close agreement with experimental values, is also presented.The dynamic range $(Dc*L)_{DR}$ refers to the range of CD variations within which the proposed approach based on a Kerr phase-interrogator can monitor, and is not limited by theequipment that comprises

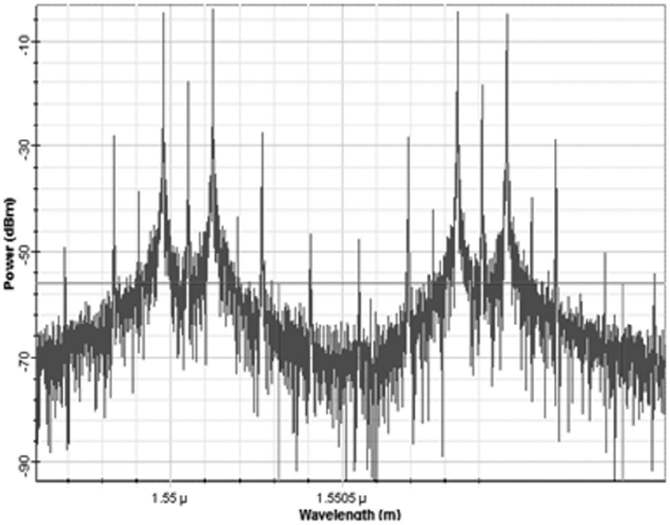

**Figure 6: Measured spectra at the output of the kerr medium**

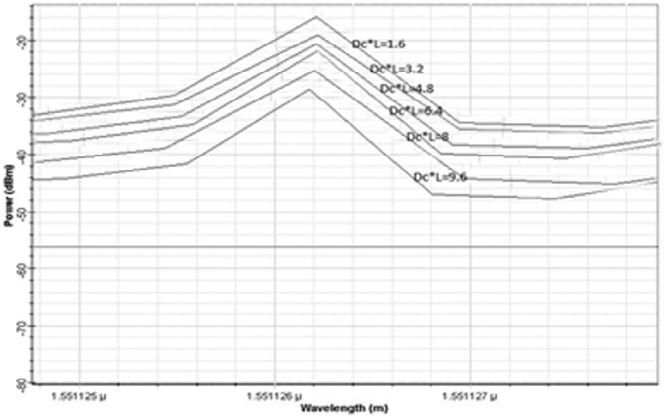

**Figure 7: A magnified image of the first-order sideband**

the CD monitor.In practice, a value of P1 corresponds to multiple values of the accumulated CD due to the sinusoidalvariation of P1 with Dc*L. To avoid post-measurement signal processing and obtain a one-to-one correspondence between $P_1$ and Dc*L, the dynamic-range $(Dc*L)_{DR}$ is restricted within thequasi-linear range over which P1 changes from the given points as shown in fig. 8.

## 5. HNLF USED AS KERR MEDIUM

In the above setup DSF isused as a kerr medium. In this case, fluctuations of P1 are induced by the noise in the peak power of the combined sinusoidal optical signal at the input of the kerr medium.The peak power noise arises from the intensity noise of the laser and the amplified spontaneous noise of the EDFA.Peak power noise also arises from external mechanical and thermal disturbances that cause birefringence variation which induce polarization variation on sinusoidal optical signals before

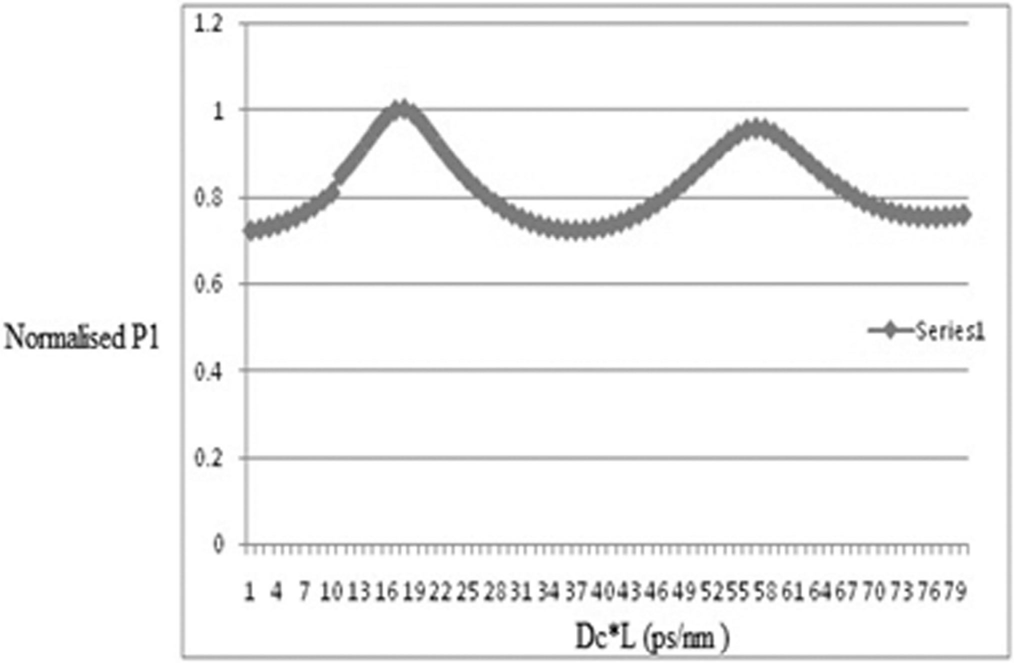

Figure 8: Normalised power as a function of accumulated CD

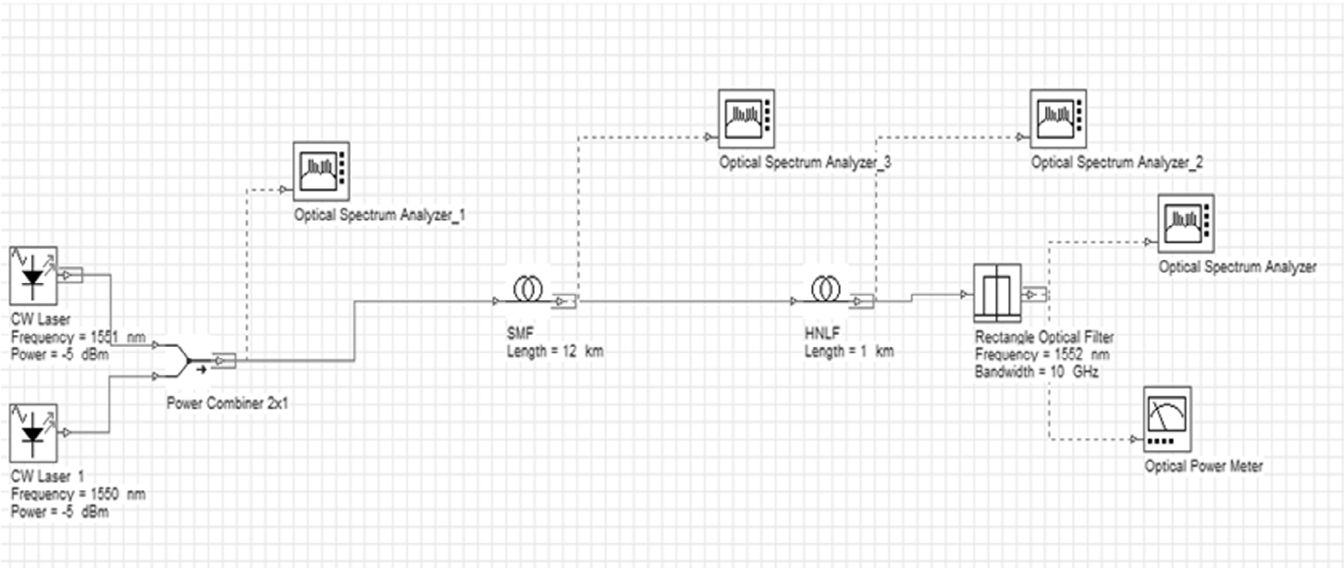

Figure 9: Simulation setup of CD monitoring using HNLF as Kerr medium

PBC.The noise of peak power induces variations which lead to fluctuations in the power of first order sideband. The noise of the photo-detector further increases themagnitude of power of first order sideband.

The resulting power leads to phase fluctuations, which limit the minimum resolvable differential phase shift and consequently limit the resolution. The magnitude of power can be reduced by utilization of a laser with low intensity noise, a highly nonlinearkerr medium to eliminate the need for the EDFA and a low noise photo-detector. Further, external disturbances that cause polarization variation are relatively slow and theircontribution to power can be eliminated by using a feedback control system that correctsthe polarization of the sinusoidal optical signals. The simulation setup of CD monitoring is shown in fig 9. The operating wavelengths of laser are set to $\lambda_1$ = 1551nm and $\lambda_2$ = 1550 nm are combined and the output of optical spectra of power combiner as shown in fig. 10.

The signals of laser then propagate through a single mode fiber, that induces an accumulated CD equivalent to $D_c*L = t_d/\Delta\lambda_{1,}$ where $D_c$ is the CD parameter $L$ is the propagation distance, $t_d = t_2 - t_1$ is the group delay difference of two sinusoidal signals induced by single mode fiber with $t_j$ beingthe group-delay caused by the sinusoidal signal carried by laser carrier at $\lambda_j$ and $\Delta\lambda_{1=}\lambda_2-\lambda_1$ is the laser carrier separation.

Then the output of single mode fiber launched through a kerr medium comprised of a highly nonlinear fiber (HNLF) with length of 1 km, the dispersion impact of kerr medium on the sinusoidal variation of power is neglected. The first order sideband generated in the kerr medium is extracted by a rectangle optical filter with 3db bandwidth of3 GHz and a power meter used to measure power as length is varied in single mode fiber.The accumulated CD is varied from16 ps/nm to192 ps/nm and the spectrum of the signal at the output of the Kerr medium is measured by an optical spectrum analyzer as shown in fig 11. The normalized power obtained as the accumulated CD is varied from 16 ps/nm to 192 ps/nm.Between these variations of CD, the conversion efficiency obtained in the range of 0.9984 to 0.9989.Thus by using highly nonlinear fiber instead of DSF, it doesn't need EDFA so it reduces the circuit complexity.In addition, noise is also eliminated due to removal of EDFA.By using HNLF, it increases the conversion efficiency.

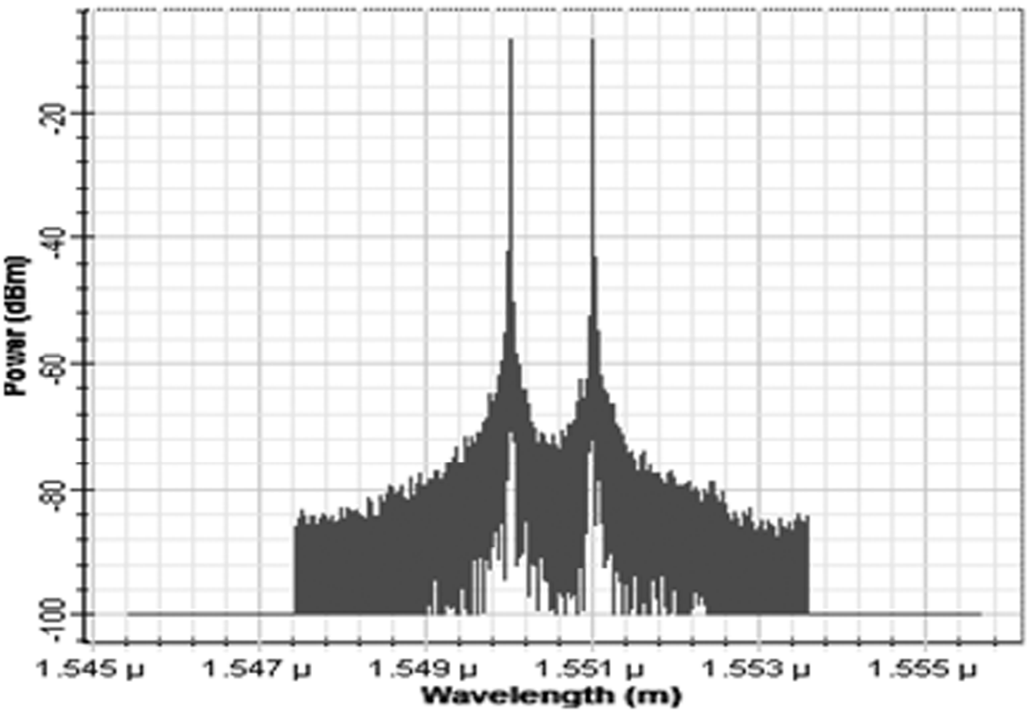

**Figure 10: Measured spectra at the output of the laser**

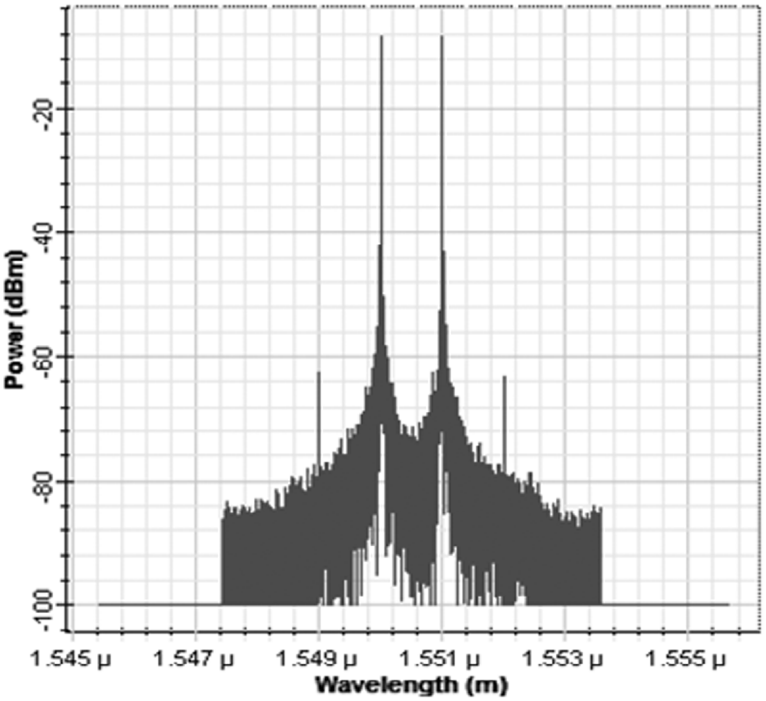

**Figure 11: Measured spectra at the output of the kerr medium**

## 6. CONCLUSION

In this paper, aCD monitoring by four wave mixing technique using kerr phase interrogator has demonstrated. The theory of FWM is employed to investigate the CD impact on the nonlinear interaction between two sinusoidal signals with different carrier-wavelengths. CD induced group-delay difference between these two different wavelengths is converted to power variation by a kerr phase interrogator. In case of DSF, the normalized power obtained as the accumulated CD is varied from 1.6 ps/nm to 9.6 ps/nm.Between these variations of CD, the conversion efficiency obtained in the range of 0.7206 to 0.7523. In case of HNLF, the conversion efficiency is obtained as 0.9984 to 09989. Thus high resolution CD monitoring opens ways for novel sensing applications and also this analytical model provides insight into CD impact on the operation of the Kerr phase-interrogator and the tools required for the optimization of the performance of Kerr phase-interrogator based sensing devices.

## REFERENCES

[1] W. H. Hatton and M. Nisimura, "Temperature dependence of chromatic dispersion in single mode fibers," J. Lightw Technol., vol. 4, no. 10, pp. 1552-1555, Oct. 1986.

[2] D. C. Kilper et al., "Optical performance monitoring," J. Lightw. Technol., vol. 22, no. 1, pp. 294-304, Jan. 2004.

[3] Kuen ting tsai and Winston I.Way, "Chromatic dispersion monitoring using an optical-and-add filter," journal of lightwave technology, vol. 23, no. 11, Nov. 2005.

[4] A.L. Campillo, "Chromatic dispersion monitoring technique based on phasesensitivedetection,"IEEEPhoton.Technol.Lett., vol. 17, no. 6, pp. 1241-1243, Jun. 2005.

[5] S.M.O. Motaghian Nezam, J.E. Mc. Ceehan and A.E. Willner, "Chromatic dispersion monitoring using partial optical filtering and phase shift detection of bit rate and doubled half bit rate frequency components," Willner, 2004.

[6] J.Yang1, L.Zhang1, T.Wul, X.Wul, L.C. Christen, S. Nucciol, O.F. Yilmazl, W.R. Peng 2 and A.E. Willner 1, "Chromatic dispersion monitoring of 40 Gb/s RZ-DPSK and 80 Gb/s RZ-DPSK data using cross phase modulation in highly non linear fiber and a simple power monitor," 2008.

[7] H. Kawakami, E.Yoshida, H. Habota and Y. Miyamoto, "Novel signed Chromatic dispersion monitoring based on asymmetric waveform distortion in DQPSK receiver," OECC, Wek-3, 2008.

[8] Z. Li and G. Li, In Line performance monitoring for RZ-DPSK signals using asynchronous amplitude histogram evaluation," IEEE Photon. Technol. Lett 8(3), 472-474, 2006.

[9] S.D. Dods and T.B. Anderson, “Optical performance monitoring technique using delay tap asynchronous waveform sampling,” OFC, OthP5, 2006.

[10] Zhaohui Li, Zhao Jian, P.K.A.Wai, “Signed Chromatic dispersion monitoring of 100 Gbit/s CS-RZ DQPSK signal by evaluating the asymmetry ratio of delay tap sampling, “vol. 18, no. 3/ OPTIC EXPRESS 3149, 2010.

[11] F. N. Khan, A. P. T. Lau, C. Lu, and P. K. A. Wai, “Chromatic dispersion monitoring for multiple modulation formats and data rates using sideband optical filtering and asynchronous amplitude sampling technique,” Opt. Exp.,

[12] C. Baker, Y. Lu, J. Song, and X. Bao, “Incoherent optical frequency domain reflectometry based on a Kerr phaseinterrogator,”Opt. Exp., vol. 22, no. 13, pp. 15 370-15 375, Jun. 2014.

[13] C. Baker, Y. Lu, and X. Bao, “Chromatic-dispersion measurement by modulation phase-shift method using a Kerr phase-interrogator,” Opt. Exp., vol. 22, no. 19, pp. 22 314-22 319, Sep. 2014.

[14] Y. Lu, C. Baker, L. Chen, and X. Bao, “Group-delay based temperature sensing in linearly-chirped fiber Bragg gratings using a Kerr phase-interrogator,” J. Lightw. Technol., vol. 33, no. 2, pp. 381-385, Jan. 2015.