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Design and Implementation of All-Optical Tunable Delay by the Combination of Wavelength Conversion and Fiber Dispersion

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ABSTRACT

In this paper we have designed and implemented an all-optical tunable delay element using the combination of wavelength conversion and fiber dispersion. We present wavelength conversion method that show with FWM. The characteristics of the proposed all-optical based techniques for tunable delay element are discussed theoretically and demonstrated experimentally. This element operates near 1550nm and generates delay time range is 2430ps.

KEYWORDS: *Tunable Optical Delay, Four Wave Mixing (FWM), Wavelength Conversion, Fiber Dispersion*

I. INTRODUCTION

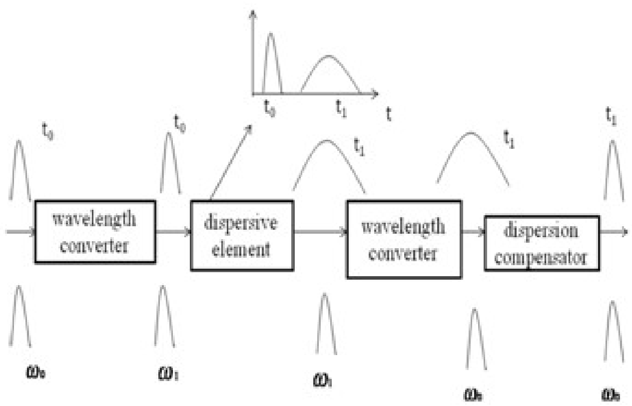
Optically-controlled time delays can play important roles in optical communication and sensor applications including optical coherence tomography[1,3], all-optical buffers and phased-array antennas. Various types of delay schemes using optical fibers have been proposed based on chirped fiber Bragg gratings [2], temporal gratings [4], wavelength conversion with dispersive media [5], and slow light propagation[6]. Each of these approaches shows advantages and drawbacks in terms of the amount of delay, the accuracy of control, the speed of operation, the distortion of pulse, and the structural complexity [7]. For example, the method based on the wavelength conversion can offer a large amount of fractional delays while the operation speed is limited owing to the use of tunable optical filters [6,7]. On the contrary, the slow light-based scheme, which has been among the hot issues inrecent studies, can provide a simple and high speedoperation, while suffering from a practica limitation in the maximum amount of fractional delays [6,8].

In this method, tunable time-slot-interchange of 10-Gb/s optical data packets using a conversion-plus-dispersion-based nearly 1000ps optical delay element is demonstrated. The input signal is converted to different wavelengths using four-wave-mixing (FWM) in highly-nonlinear-fiber (HNLF), along with a reference signal containing the two extracted signals. The two signals are retarded and advanced relative to the reference signal using a dispersion module (SMF). Moreover, the conversion wavelength is converted back to the original wavelength reusing four-wave-mixing (FWM). And, this signal will have dispersion .This dispersion is eliminated with dispersion compensation module (DCF) .The performance of the system is characterized through BER using a pseudo–random-bit-sequence (PRBS) and a BER= 10^{-9} is achieved.

II. all-optical tunable delay

Tunable all optical delay can make with many methods. Tunable optical delays have been demonstrated in the past using various methods ,including (1) optical switching in combination with a discrete set of fixed delays(2) slow-light-based photonic resonances[6] and (3)chromatic dispersion based delay coupled with tunable wavelength converters[5]. The techniques utilize wavelength dependent delay of chromatic dispersion coupled with tunable wavelength conversion to achieve relatively large tunable delays.

In this system, tunable optical delay is implemented by using the combination of wavelength conversion and fiber dispersion. Wavelength conversion method is used by four –wave mixing method (FWM). Fiber dispersion module used with single mode fiber (SSMF). Wavelength converter reused to receive the original input signal. Dispersion compensator used to compensate the dispersion that appears due to the dispersive element.



Fig(1)Generics block diagram of tunable all optical delay by the combination of wavelength conversion and fiber dispersion

Calculation of tunable optical delay;

$\Delta t = DL\Delta\lambda$

Tunable optical delay = converted wavelength dispersion × fiber length× tuning range of conversion

Shown in fig(1) is the principle of proposed system. The input signal (t_0) transmits in the wavelength converter.It uses to convert wave by using the method of four-wave mixing (FWM) method.Optical fiber need to change the signal.The signal (t_1) can be converted in the wavelength converter.After, this signal passes through the dispersive element via single mode fiber (SMF). This applied (t_1) signal again flows in the wavelength converter to receive original signal.This again used dispersion compensating module (DCF) to eliminate dispersion due to the dispersive element. Finally, the original signal (t_1) with optical delay is received again.

III. principle of proposed system

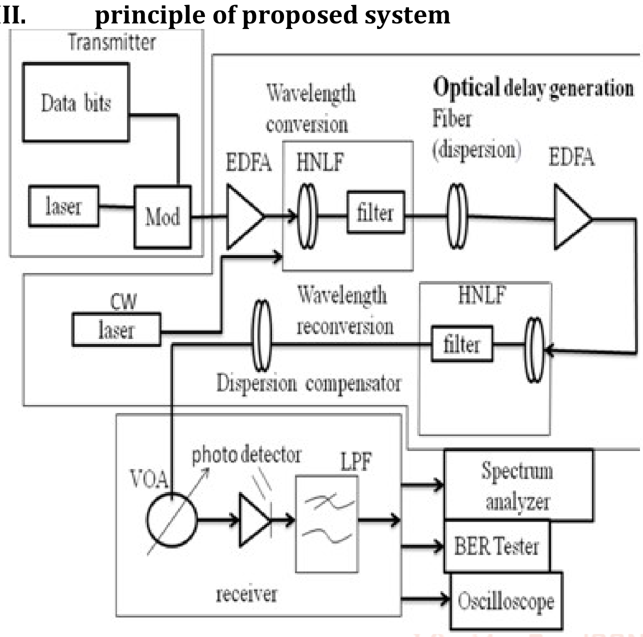


Figure2. Setup of all-optical tunable delay by the combination of wavelength conversion and fiber dispersion; EDFA , erbium-doped fiber amplifier ; HNLF ; highly nonlinear fiber ; Mod , modulator ; BER, bit error rate; CW , continuous wave

Figure (2) shows setup the block diagram of all-optical tunable delay. Firstly, the part of transmitter includes data bits, laser and modulator. Modulator operates to transfer the electrical signal to optical signal. In the part of optical delay generation, components include the combination of wavelength conversion and fiber dispersion. Moreover, this part include wavelength reconversion and dispersion compensator module. Wavelength converter is used to convert the tuning range of conversion. Fiber dispersion module used with single mode fiber (SSMF). Wavelength reconverted to original signal by using the wavelength reconversion method. Dispersion compensation module used the dispersion compensating fiber (DCF). The part receiver includes components that measure the output signal.

IV. Four wave mixing method in wavelength conversion

When wavelength channels are located near the zero-dispersion point, three optical frequencies (v_i, vj, vk) will mix to produce a fourth inter modulation product v_{ijk} given by

$$V_{ijk} = v_i + v_j - v_k \qquad \text{with } i, j \neq k$$

A simple example has two waves at frequencies v_1 and v_2. They mix and generate sidebands at $2v_1$-v_2 and $2v_2$-v_1. FWM needs the same phase of two signals. If the channels are equally spaced, a number of the new waves will have the same frequencies as the injected signals. The original signal waves can strictly multi channel system performance. The efficiency of four-wave mixing depends on fiber dispersion and the channel spacing [5, 7]. The dispersion varies with wavelength, the signal waves and the generated waves have different group velocities. In FWM, if intensity is strong, new waves will emit. Its main advantage is used in wavelength conversion. This drawback has loss and lower conversion range efficiency.

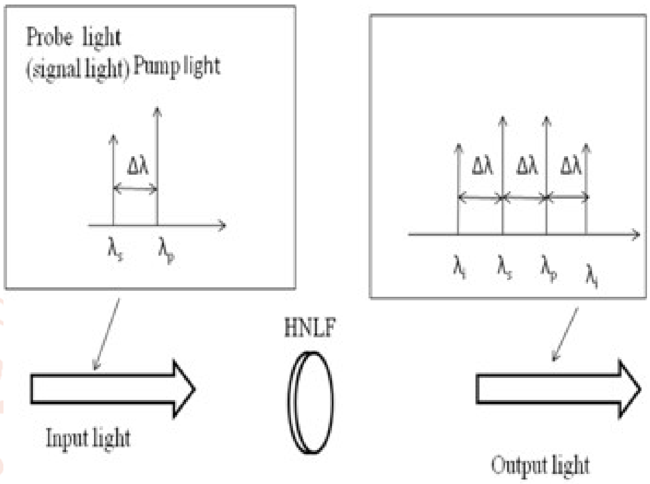


Figure3. operation of four- wave mixing with HNLF

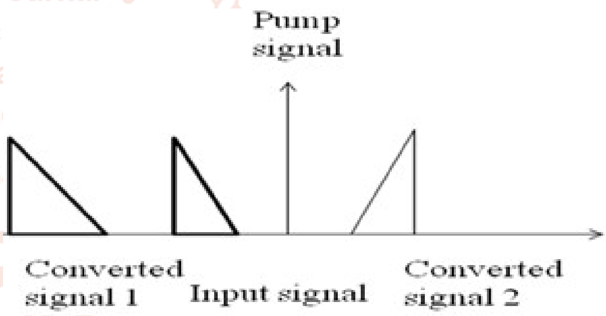


Figure4. Illustration of FWM method

Figure (4) shows the FWM method. In this figure, we can choose the desirable converted signal. If we choose the left hand side of the converted signal, this method can make the signal degeneration. If not, we choose the right hand side of the converted signal; this method can use the phase conjugation. In this system, we use the signal degeneration method. So, this system used the dispersion compensating module is dispersion compensating fiber (DCF).

V. Experimental setup and results

The experimental setup is shown in fig (5).The RZ 10-Gb/s data packet and the packet guard time of empty space is 7 bits. Packets are generated electronically and drive Mach-Zehnder intensity modulators. We manually programmed the pulse pattern generator (PPG) in order to generate the stream of data packets, and the BERs were measured by programming the PPG and error detector accordingly. The 6.0270332-km DCF has a total dispersion of – 521.7ps/nm km at 1559.9 nm and dispersion slope of -0.075ps/nm2/km. The single mode fiber (SMF) has a positive dispersion of +521.7ps/nm km, a 0.4-nm bandwidth at 1558.7 nm, and wavelength converter-1 and wavelength converter-2 has wavelengths of 1558.7nm and 1549.9 nm, respectively. Laser diode (LD) λpump-1and LD λpump-2 is fixed at 1554.3nm and 1567.5 nm, respectively. LD λ pump-1and LD λ pump-2 are tuned according to the desired converted wavelength, λc. The input powers are: (i) for wavelength converter-1, λ1 and λpump-1are each 0 dBm, and (ii) for wavelength converter - 2, λ2 and λpump-2 are 7dBm and 0dBm. The converted wavelength is -1.2 dBm for wavelength converter-1 and 3.64 dBm for wavelength converter-2. The filters at the output of wavelength converter-1 and wavelength converter -2 have 3-dB bandwidths of each 0.4nm, respectively. The receiver is a 10-Gbit/s p-i-n device.

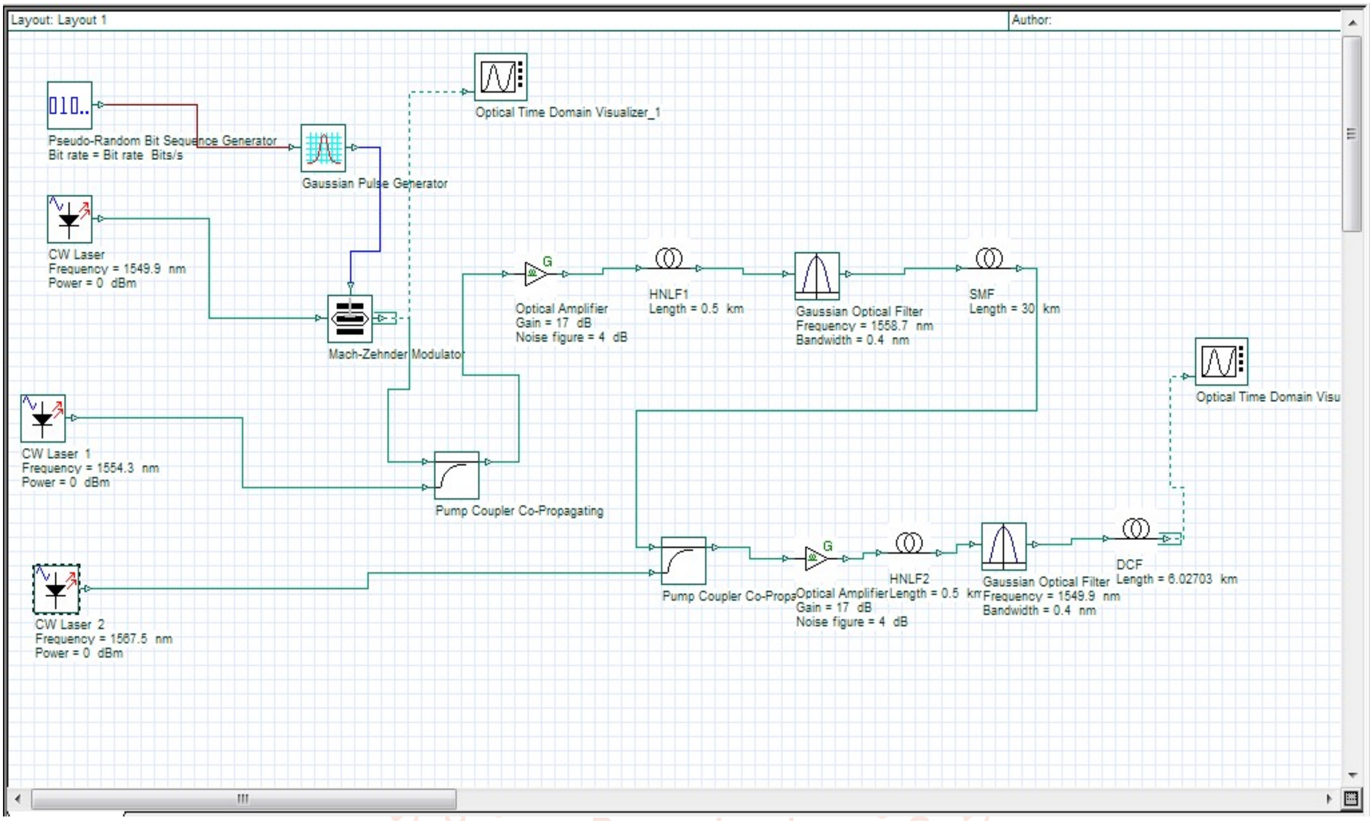


Figure (5) Tunable all-optical delay using opti system software

A. Simulation parameter details in proposed system

In the proposed system, input signal have wavelength parameter value is 1549.9nm. This signal have laser power value is 0dBm. We take the pump signal wavelength value 1554.3nm and laser power value is 0dBm. Typically, in this system take the erbium doped fiber amplifier (EDFA) of noise figure (NF) and insertion loss (IL) is 4dB and 3dB at all devices. The gain value of EDFA1 and EDFA2 are 17 dB. And, highly nonlinear fiber (HNLF) is used for wavelength conversion method of four wave mixing. HNLF include the following parameter zero dispersion wavelength is 1553nm, fiber length is 0.5km. And, HNLF determined the value of attenuation, dispersion slope. So, attenuation value is 0.47dB/km, dispersion slope value is 0.032ps/nm^{2}km. And, dispersion fiber module used single mode fiber (SSMF) .SSMF of fiber length's 30km is used for this system. For the SSMF of dispersion value are taken from file of opti- system. So, dispersion value for the conversion range value 1558.7nm is+17.39 ps/nm km. And this system used the wavelength reconversion method. For the wavelength reconversion, pump signal value are taken 1567.5nm. Moreover, in this system used the band pass filter (BPF). Band pass filter (BPF) used to filter the desired wavelength. In this system, BPFs wavelength takes the value of 0.4nm. Finally, this system includes compensating due to the dispersion module used dispersion compensating module. Dispersion compensating module used with dispersion compensating fiber (DCF).This fiber length used 6.0270332km.This fiber of dispersion value is
- 86.8ps /nm km.

B. Performance of proposed system

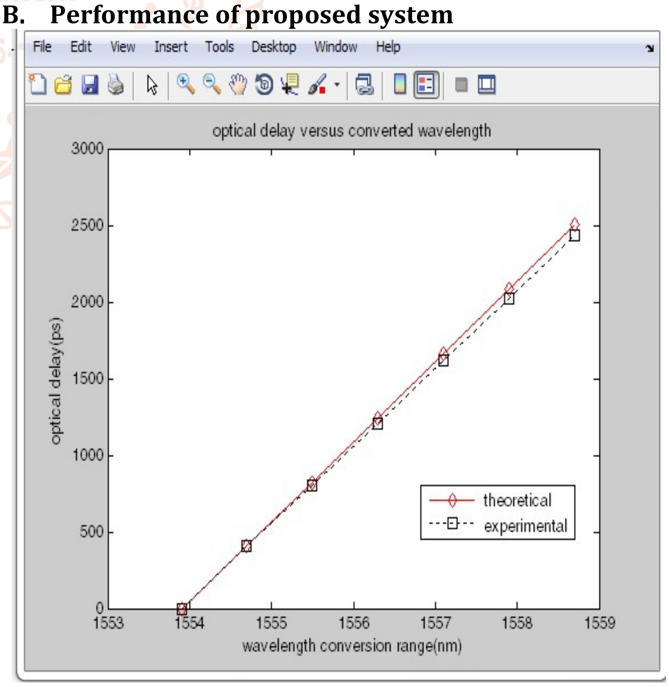
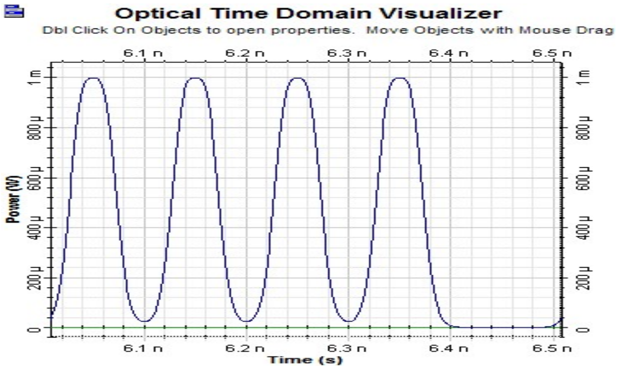
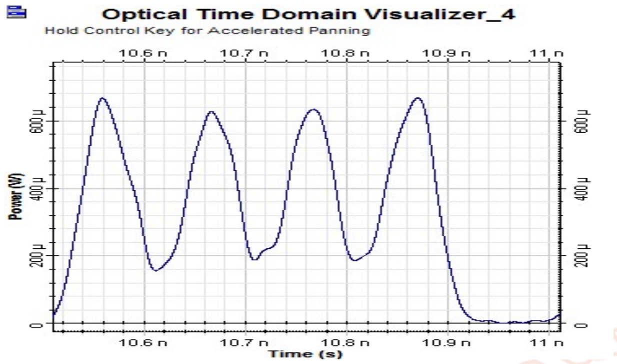


Figure (6) comparison of theoretical and experimental result of tunable all-optical delay

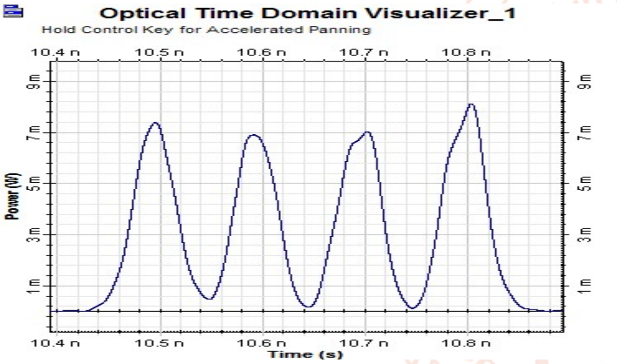
In the figure (6) shows the comparison of theoretical and experimental result of tunable optical delay. Delay time of theoretical performance a little more than the delay time of experimental performance. Due to the fiber loss and insertion loss are determined in the experimental setup.



(a)



(b)



(c)

Figure (7) Illustrate delay and dispersion of converted signal 1558.7nm (a) input signal 1549.9nm (b) Without dispersion compensation of converted signal 1558.7n (c) After reconversion and dispersion compensation of converted signal

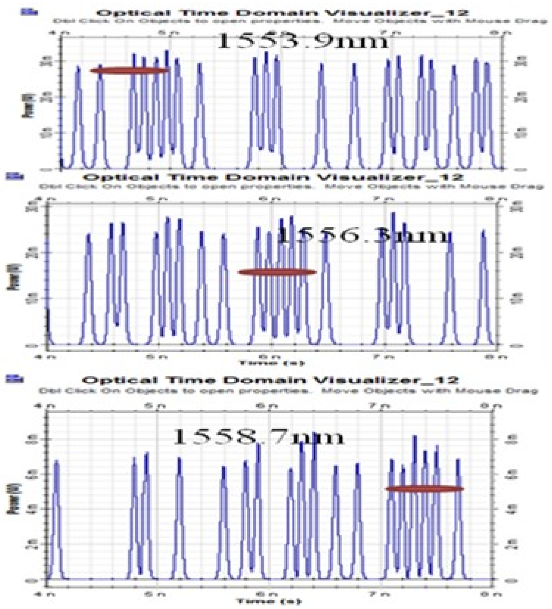
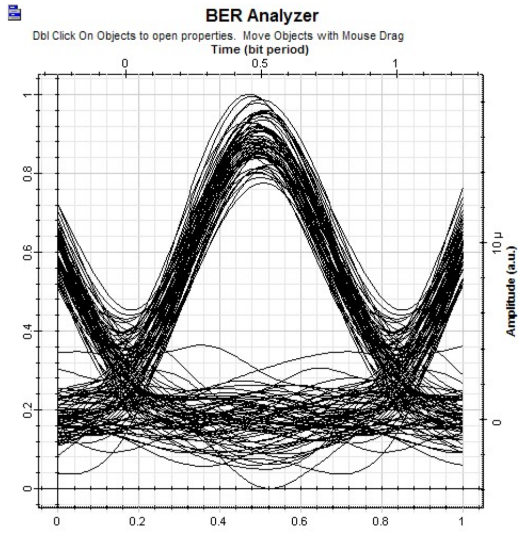
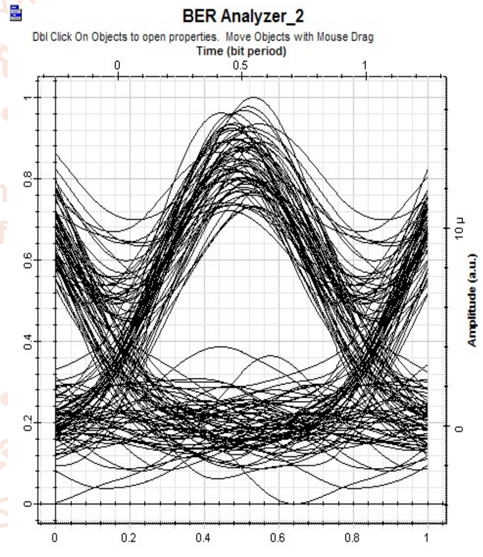


Figure (8) tunable all- optical delay versus conversion range (at 1553.9nm, 1556.3nm and 1559.5nm)

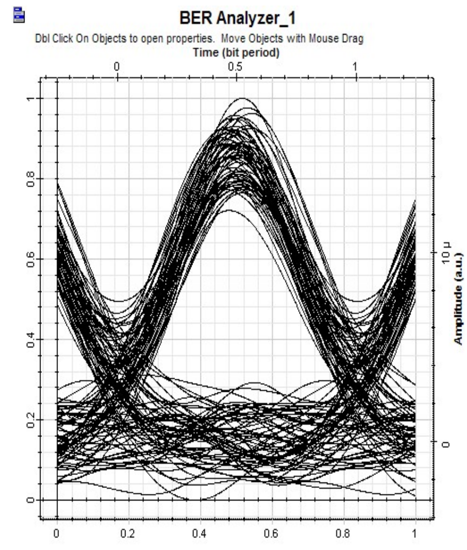
Figure (8) show the delay time versus conversion range. At the converted signal 1553.9nm delay time range Δt is 0ps.And converted signal 1556.3nm delay time range, Δt have got 1210ps .At the converted signal 1558.7nm, delay time range Δt=2430ps.In this signal, conversion range value is 4.8nm and dispersion value is +17.39ps/nm km.



(i)



(ii)



(iii)

Figure (9a) comparison of eye diagram (i)at back to back (ii)before dispersion compensation (iii)after dispersion compensated

Figure (9a) indicates the comparison of eye diagram. At the received power -23.5dBm,the peformance of fig (iii) is better than the fig (ii). The performance show the standard BER $=10^{-9}$ and Q factor value have approximately 6.

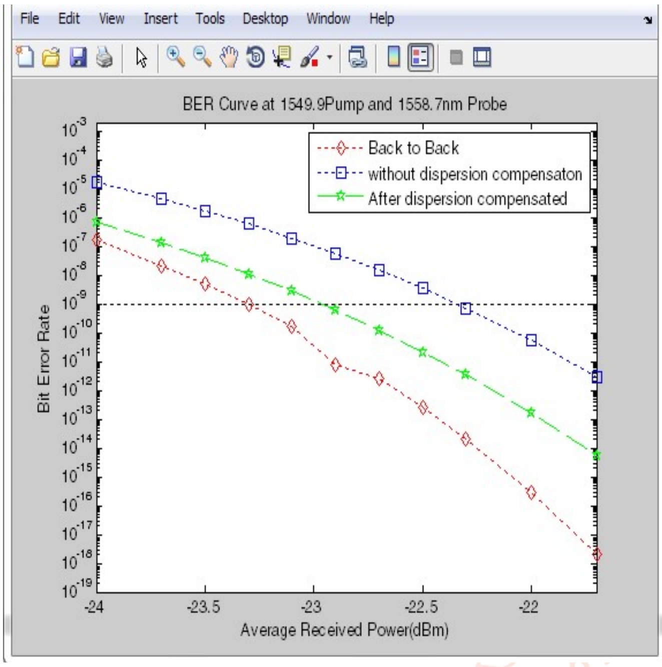


Figure (9b) performance of the BER curve versus received power

Figure (9b) illustrates the performance of the BER curve versus received power. In this system, the performance of the value after dispersion compensated is better than without dispersion compensated.

VI. Conclusions

We have demonstrated a novel tunable all-optical delay scheme based on wavelength conversion, dispersion, and reconversion. Optical delay can have change versus of the fiber length and pump wavelength. And it is tuning the wide range of signal pulse .This research shows tunable optical delay by using the OptiSystem software .So, optical delay is important in optical system due to these above factors. In this proposed method, system was used wavelength converter and dispersive element to generate tunable optical delay. Wavelength converter can be implemented by using the four wave mixing method .This system can be converted wavelength conversion range Δλ=4.8nm and dispersive element uses single mode fiber, dispersion has +17.39ps/nm km .In this experimental system, optical delay tuning range can attain 2430ps.This system characterized the impact of the system on performance by measuring the BER and power penalty have 0.4dBm after dispersion compensated. Before the dispersion compensation, power penalty have 1dBm.

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