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Measurement of Tunable Optical Delay Using Wavelength Conversion and Fiber Dispersion

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Abstract

In fiber communication system, delay elements are essential for coherent receivers and in the situation of time division multiplexing. Optical communication is transmitted with light. It has a propagation delay. So, in this system, the performance of optical delay element is demonstrated on wavelength conversion, effects of single mode fiber (SMF) dispersion and fiber length. A numerical simulation is used to predict the performance of delay element for different experimental conditions. It has been proven that when the wavelength is changed and its element covers the entire C band. The system is used with the suitable optical pump power and various fiber lengths. It is accomplished with the various parameters by using Opti-system Software. The system operates near 1550 nm and generates delays time approximately 2.65 nanoseconds. In this paper, the performance value is also stated the table which is comparison of theorical result and practical result of delay time.

Key Words: time division multiplexing; wavelength conversion; single mode fiber (SMF); C-band; fiber length

1. Introduction

The ability to buffer or delay information is highly desirable in communication. Specific applications discussed include network buffering, data synchro-nization, and time division multiplexing. While information is transmitted using optical fibers in the stream communication networks require optical/ electronic computer components. Altering information creates a bottleneck for future growth in data transfer a report [6]. Among other things, it is also important to construct observable light delay lines. The techniques such as optical coherence tomography [2] and phased array light control, radio communication antenna [4], light detection reconnaissance (LIDAR) [3], optical sampling [11], process interface [9].

Today, several techniques have been used to demonstrate tunable optical delays, including (i) selecting among a discrete set of optical propagation paths, which produces only a finite set of delays [7]; (ii) using slow light-based photonic resonances, in which delays tend to be <1 ns for Gbit/s signals [1]; and (iii) wavelength conversion coupled with chromatic dispersion [5–12]. This latter method uses a combination of wavelength conversion with inter-channel chromatic dispersion and inter-channel dispersion compensation. With a continuous-wave (CW) optical input, this thermal nonlinear effect can dominate over the carrier nonlinear effect with proper device size, and the effect possesses the lowest power requirement relative to other optical tuning mechanisms [8], [10].

This system proposes a novel wavelength conversion and dispersion technique for all optical delays. For wavelength conversion, use the numerical value in application software. Using this delay scheme, validate This system drastically increases the range of achievable delays; while maintaining the original wavelength to the converted wavelength is increased and the value of fiber length is increased.

2. Methodology

The proposed system designed by using the combination of wavelength conversion and fiber dispersion technique. Wavelength conversion method is used with the numerical value in application software. Fiber dispersion module used with single mode fiber (SMF).

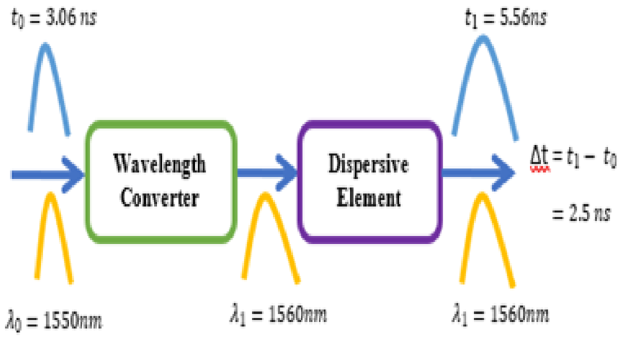


Figure 1. Block Diagram of Tunable Optical Delay

Figure 1 shows the generic block diagram of optical delay element using wavelength conversion and fiber dispersion. Before the wavelength conversion, the input signal is considered with λ_0=1550 nm at C-band. At this input signal, t_0 value is 3.06ns. The input signal converts to a converted wavelength (λ_1=1560 nm) by using the numerical value in Opti-system Software . After the wavelength conversion, (λ_1) the dispersive element is considered with single mode fiber for the dispersion and fiber length. Finally,the t_0 value is attained the t_1=5.56ns by using the wavelength conversion and fiber dispersion. So, the difference between the value of t_0 and t_1 of delay time (Δt) is got 2.5ns. The proposed system's wavelengths difference, which are being tested in the Opti System Software, are illustrated in Table 1.

Table 1. Difference Wavelengths of Proposed System

Wavelength, λ_0 (nm)	Converted Wavelength, λ_1 (nm)	Dispersive Element, D ps/nm/km	Time, t_0 (ns)	Time, t_1 (ns)
1550	1560	16.75 at L=15km	3.06	5.65
1550	1557	16.75 at L=15km	3.06	4.84
1550	1560	16.75 at L=7 km	3.06	4.48

Calculation of tunable optical delay is

$$\Delta t = D \times L \times \Delta\lambda \quad (1)$$

where, Tunable Optical Delay = Dispersion × Fiber Length × Wavelength Conversion

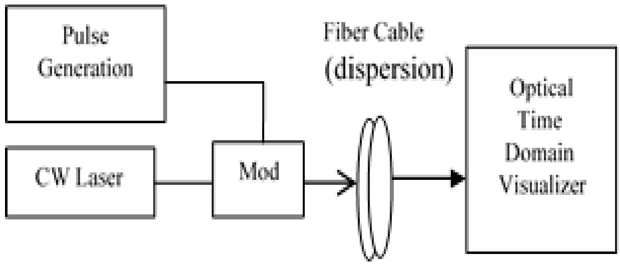


Figure 2. System of Optical Tunable Delay

The system diagram for the tunable optical delay system is shown in Figure 2. The portion of the transmitter part include the combination of signal pulse generation and laser. A pulse generator is an electronic circuit or electronic test equipment used to generate square waveforms. Pulse generators are mostly used in digital circuits, while relative generators are often used in analog circuits. An ideal continuous wave (CW) laser converts low coherence input pump power into a highly coherent optical output signal that is constant in amplitude and wavelength, and the output spectral concentration is limited only by cavity loss. So, electrical signal to optical signal can be achieved by using the combination of pulse generator and CW laser that used the amplitude modulator. Optical communication systems often use amplitude modulation to encode information along with optical frequency modulation to multiplex and decode multiple different signals. And then, converted wavelength is desired the numerical values within the fiber. The fiber dispersion type is used with the single mode fiber.

Wavelength conversion typically refers to the process of changing the wavelength of light, often in the context of optical communications or nonlinear optics. In optical fibers, wavelength conversion can be achieved using nonlinear effects to improve signal transmission, reduce interference, or expand the range of wavelengths used for communication. This technique uses a nonlinear crystal to convert an input signal at one wavelength to an output signal at a different wavelength, often used in laser applications.

Wavelength conversion is crucial in telecommunications to increase bandwidth and improve signal quality, as well as in medical imaging, sensing technologies, and laser systems.

Dispersion may be cause due to the long-distance length travel along a fiber and speed not equal. Dispersive element makes to perform the optical delay by combining the wavelength conversion. It is type of fiber. In this proposed system, dispersive element is constant 16.75ps/km/nm for wavelength 1550nm. Dispersive of Single-mode fibers (SMF) achieve large transmission capacities, but can also transport coherent light, maintain the state of polarization over a longer distance and can be used for a variety of sensing applications.

3. Result and Discussion

The preparation delay element utilized in the Opti-system software is illustrated in Figure 3. The pulse generator is used with the user defined bit sequence generator. The laser is used with the CW laser at the 1550nm.The modulator is applied with the amplitude modulator. And, the dispersive element is desired with the characteristics of single mode fiber. The converted wavelength of numerical value is changed in this fiber element. The performance result is got with the optical time domain visualizer and optical spectrum analyzer.

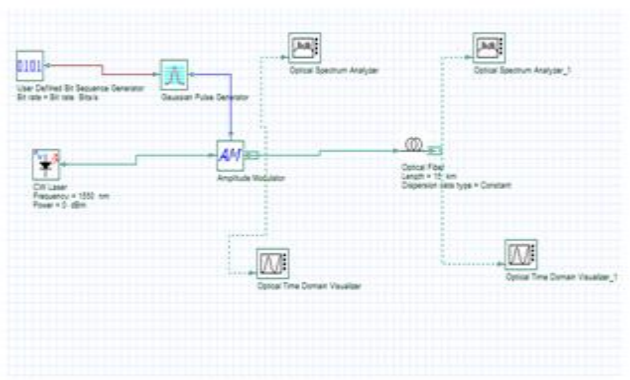


Figure 3. Setup of Delay Element Using Opti System

Designing a delay element using OptiSystem involves several key parameters and considerations. Component selection is delaying line (fiber), input source (continuous-wave (CW) laser), and amplitude modulator. Wavelength selection: choose 1550 nm for telecommunications. Input parameters are described in Table 2. Simulation settings are analysis type (frequency domain) and sampling rate (gaussian pulse generator). Output monitoring includes a photodetector to convert the optical signal to an electrical signal. These parameters in an optical system can be effectively configured to design and simulate a delay element that meets specific optical system requirements. Ensure that design is validated with tests and simulations to guarantee optimal performance.

Table 2. Design Parameters of Proposed System

Parameters	Desired value
Bit Sequence	0000001 bit
Bit Rate	10 Gbit/s
CW Laser frequency	1550 nm
Power	1 mW
Sample rate	640 GHz
Number of samples	8192
Reference Frequency	1560 nm
Fiber Length	15 km
Dispersion	16.75 ps/nm/km

3.1. Comparison of Theoretical and Simulation Results due to Wavelength Conversion

According to the performance results in Figure 4, the delay time performance is more increase, the more increase the converted wavelength. The converted wavelength condition is selected between 1550nm and 1560nm to design proposed system for simulation and theoretical calculation.

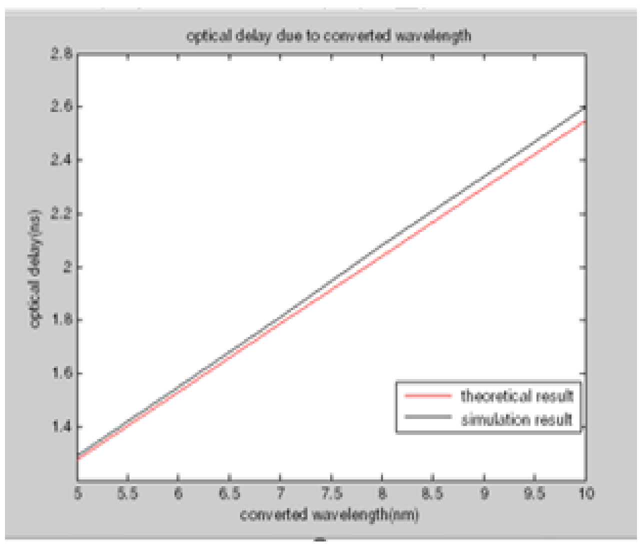


Figure 4. Delay Time Vs. Converted Wavelength Plot Due to Wavelength Conversion (Error 0.05%)

3.2. Comparison of Theoretical and Simulation Results due to Fiber Length

Figure 5 shows the result of delay time element (ns), by considering the difference length of fiber parameters. The fiber length value of 4km is not good for the delay time value. And, the fiber length value of around the 10km of delay time element value is better than the other fiber length parameter value for 1550nm application. So, the fiber length around the 10km is selected. At the fiber length value is 15km and the wavelength conversion value is 10nm, the delay time value is achieved 2.59ns. According to Figure 5, the comparison of theoretical and simulation results has the gap of these results are only 0.03% because of simulation performance is 1.9ns and theoretical is 0.87ns. It is contracted to the approximately of theoretical results and simulation results.

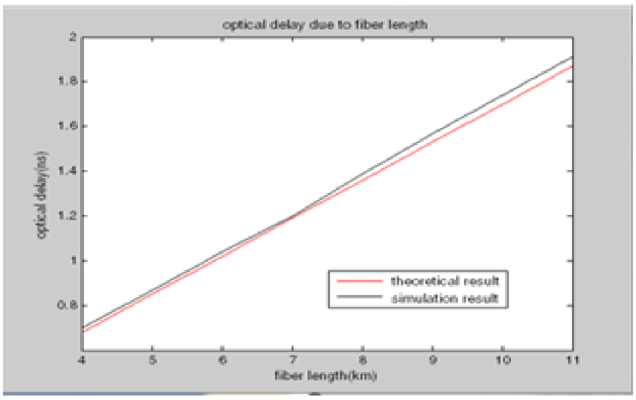
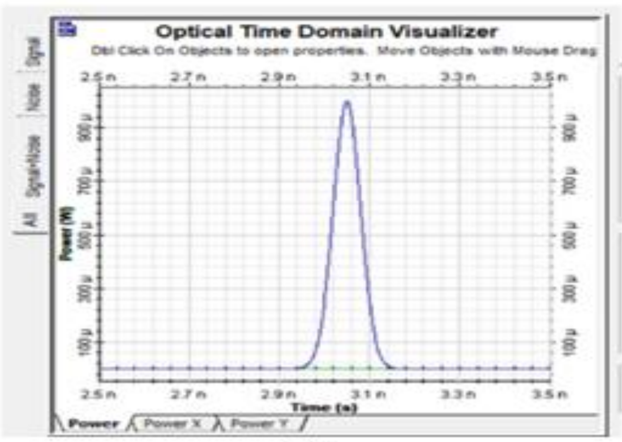
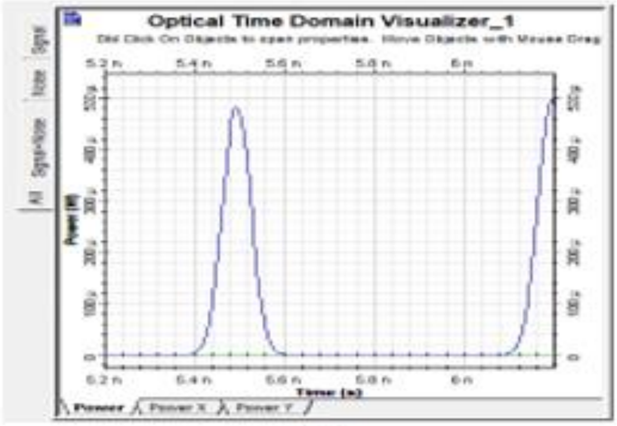


Figure 5. Delay Time Vs. Converted Wavelength Plot Due to Fiber Length (Error 0.03%)

In Figure 6, the input signal is 3.06ns and the output delay signal is reached the 5.65ns. So, the delay time value is achieved 2.59ns where the wavelength conversion and the fiber length value are used 10nm and 15km.

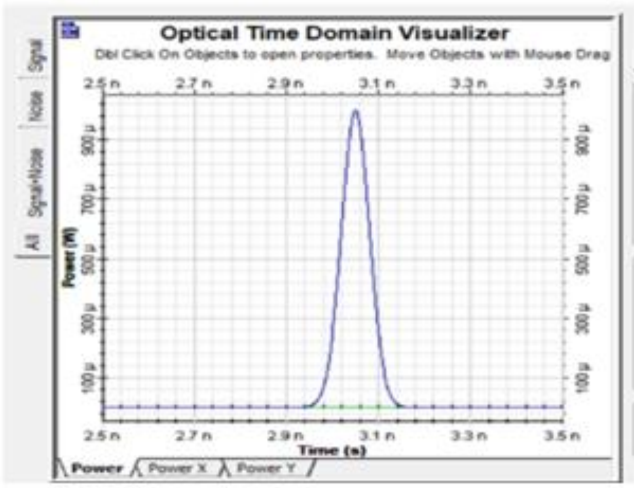


(a)

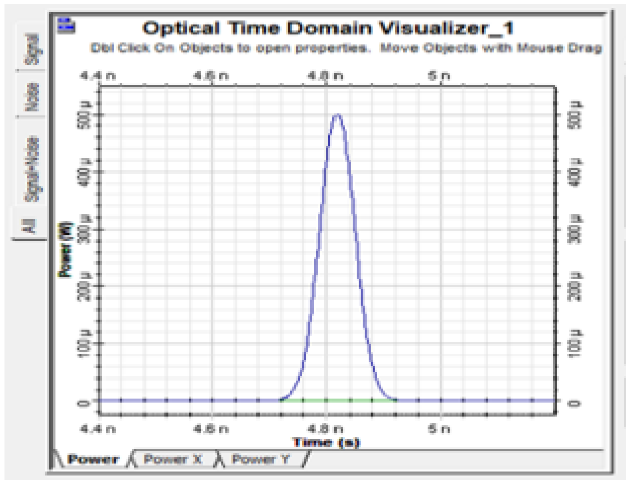


(b)

Figure 6. Performance of Input Signal and Output Delay Signal at Wavelength Converted 10nm and Fiber Length Value 15km (a) Input Signal (b) Output Delay Signal



(a)

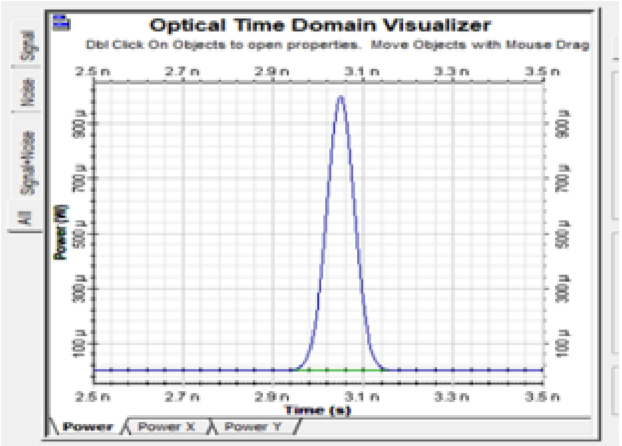


(b)

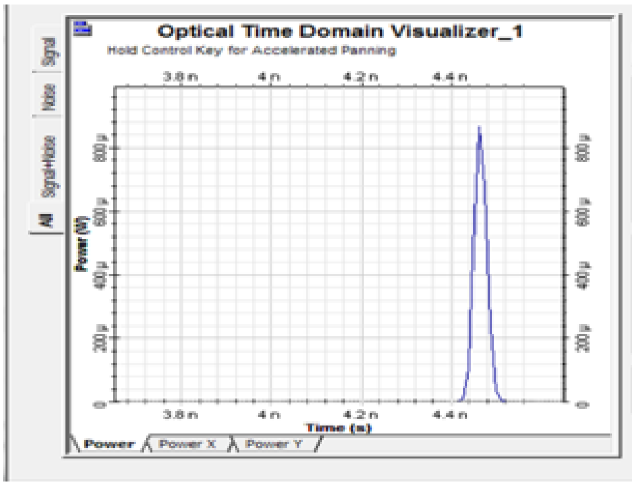
Figure 7. Performance of Input Signal and Output Delay Signal at Wavelength Converted 7nm and Fiber Length Value 15km (a) Input Signal (b) Output Delay Signal

The wavelength conversion value and the fiber length are considered with 7nm and 15km in

Figure 7. At these parameters, the inpit signal time is achieved 3.06 ns from Figure 7(a) and the output signal time signal is achieved 4.84ns from Figure 7(b). So,the delay time value is attained 1.78ns.



(a)



(b)

Figure 8. Performance of Input Signal and Output Delay Signal at Wavelength Converted 10nm and Fiber Length Value 7km (a) Input Signal (b) Output Delay Signal

In the Figure 8 shows the performance of input signal and output delay signal at wavelength conversion and fiber length. The delay time value is achieved 1.42 ns according to the result of input signal is 3.06 ns from Figure 8 (a) and the output signal is 4.48 ns from Figure 8(b). This delay time value 1.42 has been obtained by subtracting input time signal 3.06ns and output time signal 4.48ns. In this delay time value, the wavelength conversion is used with the 10nm and the fiber length is considered with the 7km.According the result, the consideration of fiber length short is achieved the scarcer signal distortion, Otherwise, if the fiber length is considered with longer and conversion length value 7nm, the delay time value is not achieved the long time.

Table 3. Test and Results of Proposed System

Wavelength Conversion, Δλ (nm)	Fiber Length, L (km)	Fiber Dispersion, D (ps/nm/km)	Optical Delay, Δt (s)
10	15	16.75	2.59
7	15	16.75	1.78
10	7	16.75	1.42

Test and results of the proposed system are listed in following Table 3, after changing various values of wavelength conversion and fiber length. According to Table 3, if the wavelength conversion and fiber length are short parameters, the delay time is achieved in a in a short time. And if the value of wavelength conversion and fiber length are longer, the delay time is more long. This design parameter is effect on wavelength conversion and fiber length. Therefore, parameters can set the value of a variety of changes and delay time as needed, so it's called tunable optical delay.

4. Conclusion

The proposed system is considered based on the delay time calculation. The delay time value is measured with the fiber dispersion, fiber length and wavelength conversion. The fiber dispersion is used with the single mode fiber dispersion 16.75ps/nm/km. The design parameter for these results of the system is that the delay time value has been 2.59 ns at the wavelength conversion is used with the 10 nm and the fiber length is 15 km from experimental results. By theorical calculation, the 2.5 ns is achieved for. So, when comparing these two experimental and theorical results, there are only 0.09 ns differences. It's almost no difference; it's almost error-free. For the application device in telecommunication that is need more delay time, the wavelength conversion and fiber length are considered with longer parameter. In other words, For the application device that is need less delay time, the wavelength conversion and fiber length are considered with shorter parameter. In this system, the comparison of theorical and simulation results are shown.

According the result, the simulation result and calculation result is attained the approximately equal. In the simulation design, the wavelength conversion value is selected the numerical value.

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