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Performance Evaluation of All Optical UWB DWDM Optical Communication System

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Abstract: In this study, we propose the design and simulation of all optical Ultra Wide Band (UWB) Dense Wavelength Division Multiplexing (DWDM) laser communication system. The proposed system was been simulated under different operation conditions. A simulated system consist of a laser sources, semiconductor optical amplifier and optical modulator. This technique based on combination of optically reconfigurable photonic microwave delay-line filter and using the cross Gain Modulation (XGM) in Semiconductor Optical Amplifier (SOA). In SOA, the cross Gain Modulation (XGM) technique was used to produce a UWB monocycle pulse with a full width at half-maximum of 30 psec. After derivative the monocycle pulse, the doublet pulses was obtained with 21 psec. All optical UWB pulses was interleaving over DWDM channels with 50 GHz channel spacing and 10 Gb/sec data rate using ON-OFF keying modulation technique.

Key words: All optical UWB, FWHM, DWDM technique, OOK modulation, monocycle, channels

INTRODUCTION

Ultra Wide Band (UWB) technology is one of the favorable technologies for many wireless communication applications that uses low power levels for sending data through a wide fraction of the spectrum of radio (Abraha *et al*., 2012). This technique become attracted large interest in recent year due to use high frequency bandwidth within unlicensed spectrum from 3.1-10.6 GHz as specified by the Federal Communication Commission FCC (Yu *et al*., 2013; Ran *et al*., 2010). The FCC organize rule the emission of the UWB system in particular wireless communication. The FCC regulated the levels of Power Spectral Density (PSD) below -41.3 dBm/MHz (Yu *et al*., 2013; Wang *et al*., 2014). UWB devices compared with other communication standards will not cause significant harmful interference due to low power level (Duraisamy, 2013). Many applications based on UWB communication has generated a lot of interest such as wireless sensor network (Carbone *et al*., 2013), high resolution ranging of the system (Ding *et al*., 2013), wireless body for sensor network (Wang *et al*., 2014) and the applications of building network (Abraha *et al*., 2012). A communication system can said to be UWB if the fractional bandwidth more than 20% of the central frequency or the instantaneous spectral occupies a 10 db bandwidth more than 500 MHz. The fractional bandwidth is define as (Ostman, 2016):

$$f_B = 2\frac{f_h - f_l}{f_h + f_l} \quad (1)$$

Recently, there is an increasing interest UWB communication in the research and development this technology for short range wireless communication which promises very large data rate, especially when integrating UWB wireless service with the large efficiency of optical system (Mehrdad, 2013). This paper study the transmission performance of multiple all optical UWB over Dense Wavelength Division Multiplexing (DWDM) laser communication system with 50 GHz channel spacing. In this work, firstly generation all optical UWB based on cross Gain Modulation (XGM) in Semiconductor Optical Amplifier (SOA), then study increase the capacity of the channel and study the possibility of distribution multi all optical UWB signals over (DWDM) with optical fiber communication system using ON-OFF Keying (OOK) modulation technique with 10 Gb/sec data rate (Bennett *et al*., 2014). The software package using on simulation performed using OptiSystem last version (14.1).

Generation of UWB pulse in optical domain: There are many methods for photonic generation of UWB monocycle and doublet pulses. The first and second order derivative of the Gaussian pulse represented Gaussian monocycle and doublet. Photonic microwave-delay line

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filter represent one of this method which attracts large interest due to different signaling formats can be acquire in optical domain. The first and the second order derivatives be approximate by the first and second-order differences. By photonic microwave delay line filter can be implemented this with two or three taps, both with one negative tap. Assume X(t) is the input Gaussian pulse is applied to a two taps microwave delay line filter as shown in Fig. 1.

The filter has one positive and one negative coefficient by Abraha *et al.* (2012). The output of the filter y (t) is given by Yao *et al.* (2007) and Wang and Yao (2007):

$$y(t) = x(t)-x(t-\tau) \tag{2}$$

Where τ is the time-delay difference. By applying Fourier transform to two side of Eq. 2, we obtain:

$$Y(f) = X(f)-e^{-j2\pi f\tau}\times X(f) \tag{3}$$

Where Y(f) and X(f) are the fourier transforms of Y(t) and X(t), respectively. One can show that:

$$\begin{aligned} Y(f) &= X(f)-e^{-j2\pi f\tau}\times X(f) \\ &= J2e^{-\frac{J2\pi f\tau}{2}}\times \sin\left(\frac{2\pi f\tau}{2}\right)\times X(f) \end{aligned}$$

By using the geometric $\sqrt{2}\sin\theta = \sqrt{1-\cos 2\theta}$ yields the:

$$Y(f) = \left[J\sqrt{2}e^{-\frac{Jw\tau}{2}}\sqrt{1-\cos 2\pi f\tau}\times X(f)\right]$$

The magnitude of frequency-response of the filter is gave by:

$$|H(f)| = \frac{Y(f)}{X(f)} = \sqrt{2-2\cos(2\pi f\tau)} \tag{4}$$

To get a spectrum corresponding UWB monocycle pulse, a filter with frequency response that can be shape the spectrum of the input Gaussian pulse can obtain by properly selecting time delay difference τ. To generate UWB doublet pulse, the second order derivative of a Gaussian pulse should be implemented which can be approximated by the second order difference (Yao *et al.*, 2007):

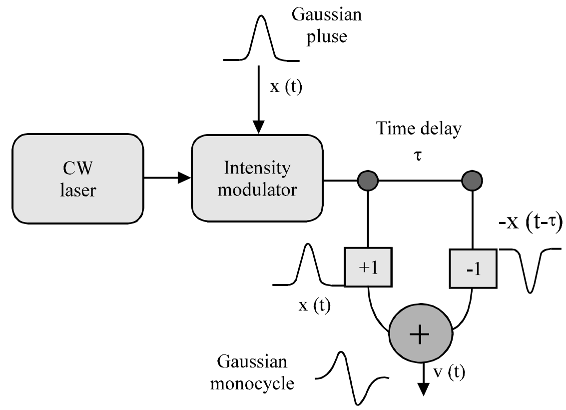

Fig. 1: UWB monocycle generation based on microwave delay-line filter

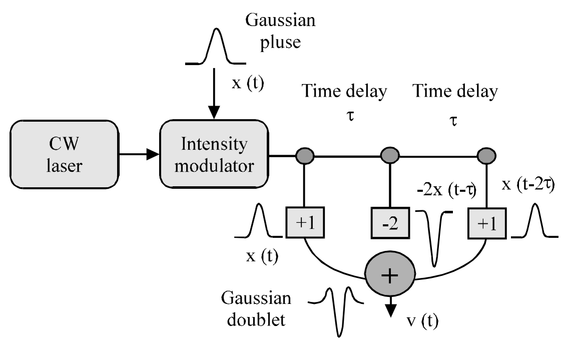

Fig. 2: UWB doublet generation based on a three-tap delay line filter

$$\begin{aligned} y(t) &= [x(t)-x(t-\tau)]-[x(t-\tau)-x(t-2\tau)] \\ &= x(t)-2x(t-\tau)+x(t-2\tau) \end{aligned} \tag{5}$$

The last equation shows that an UWB doublet signal can be generated using a microwave delay-line filter with three-taps with coefficient of [1-2 1] as shown in Fig. 2.

The frequency response of the three-tap microwave delay line is gave by:

$$|H(f)| = \left|\frac{Y(f)}{X(f)}\right| = 1-2e^{J2\pi f\tau}+e^{-2J2\pi f\tau} \tag{6}$$

Based on the cross Dain Modulation (XGM) in a Semiconductor Optical Amplifier (SOA), the negative coefficient can be generate. Figure 3 shows the block diagram of all optical UWB pulse generator.

The light generated from CW laser with constant power (5 dBm) is splitted into two branches by a Power Splitter (PS) that divided the power equally. The upper is

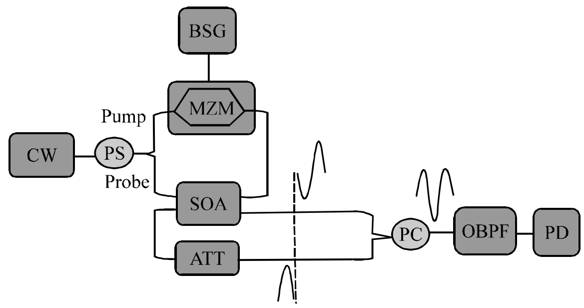

Fig. 3: Block diagram of all optical UWB pulse generator

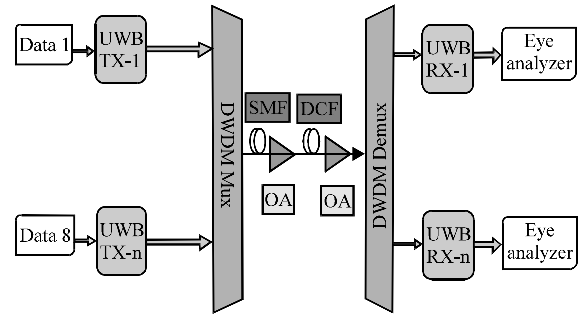

Fig. 4: The parts of the optical system

modulated through optical modulator using Bit Sequence Gaussian pulse generator (BSG) while the lower part is modulated through wide-band travelling wave SOA that represent the probe light with the signal light in opposite directions. The propagation of the probe light from left to right is amplify gradually and reached the maximum value at the right side of the SOA while the pump signal is amplify gradually from right to left to reach the maximum value at the left side of SOA. Due to XGM, the probe light has a reversed polarity in the left side of SOA because it weak while the signal light is strong. Therefore, the monocycle pulse is form due to the overshoot at the leading edge of probe-light. The gain of the leading edge of the pulse of Gaussian is larger than the gain of trailing edge lead to the pulse peak is move toward the leading edge with reversed-polarity of probe light. If superimposing occur between the attenuated-pump and probe light, the UWB doublet is been generating.

Dense Wave Division Multiplexing (DWDM): Dense wave division multiplexing is a technique that several optical signals with closely spaced wavelengths are been modulated by using independent bit streams and transmitted through single optical fiber. Growing demands of using DWDM that made using it in UWB communication system to enhance the performance. In this paper, description of outdoor DWDM based on UWB over fiber and the possibility of distributing multi all optical UWB signals over existing DWDM optical network with two value of multiplexed channel, 8 and 16 channel DWDM system. DWDM are design with 50 GHz channel spacing is use to take the simulation results and this bandwidth chosen according to International Telecommunication Union (ITU) standard for dense WDM grid (Ostman, 2016; Kiaee and Seraji, 2016). The system can be divide according to Fig. 4 in three part:

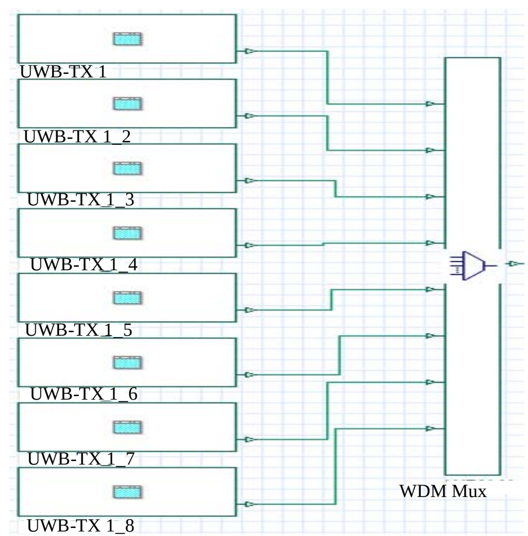

Fig. 5: Block diagram of the transmitter part for 8 channel

Table 1: Parameters of optical multiplexer and demultiplexer for dwdm system

Mux/demux		
Parameters	Value	Units
Frequency spacing	50	GHz
Bandwidth	16	GHz
Filter type	Bessel	
Filter order	2	

Transmitter structure: The output optical signal from each one of 8 or 16 transmitter is fed to the dense WDM system with the laser frequency (193.1 THz) for channel 1, (193.35 THz) for channel 8 and (193.85 THz) for channel 16. The wavelength of three channel above that corresponding the laser frequency is (1552.52, 1549.515 and 1546.51) nm, respectively. These signals are combine in one signal and propagate in optical fiber. Figure 5 shows the block diagram of the transmitter side of 8 channel DWDM system. The simulation parameter of the multiplexer used in DWDM system is shown in Table 1.

Optical fiber channel: In a single channel, the output of the multiplexer is propagate through optical fiber channel. The main aim of any communication system is to increase the transmission distance, therefore, there has been increasing interest in transmitting all optical UWB signals over long distance of existing SMF transmission link. The performance of such transmission that designed to operate at 1550 wavelength is degrade mainly by chromatic dispersion that become the major factor that restricts the long distance fiber optic system. To solve this problem, it uses Dispersion Compensation Fiber (DCF). Most research works are show that the system performance in optical networks improvement when using DCF and increased SNR (Kiaee and Seraji, 2016). The using of DCF be either pre or post DCF. In this study, it assumed that DCF is use at the end of SMF section to compensate it dispersion and the performance of this system is better than pre DCF. DCF has become a most suitable method of dispersion compensation because are more mature, stable, no easily affected by temperature and wideband width. To compensate the losses, two optical amplifier of gain G1 and G2 can be insert and can be calculated as (Singh and Singh, 2012; Kaur *et al*., 2015).

$$G = L\times\alpha \tag{7}$$

Where:

G = The gain measured in dB
L = The length measured in km
α = The losses measured in dB/km

If suppose the SMF and DCF be characterized by L_{SMF} and L_{DCF} respectively, the condition for perfect dispersion compensation is:

$$D_{SMF}\times L_{SMF}+D_{DCF}\times L_{DCF} = 0 \tag{8}$$

That mean the length of the DCF should be chose to satisfy:

$$L_{DCF} = -\frac{D_{SMF}}{D_{DCF}}\times L_{SMF}$$

The length of the DCF can be a part of the transmission link length. At the 1550 nm, to compensate the positive dispersion of SMF, conventional dispersion compensating fiber have a high negative dispersion between (-75-90) psec/nm/km. The parameter values that used in the simulation in SMF and DCF in Table 2.

Receiver structure: After propagation of UWB signal through optical fiber channel, it then received and detected in the receiver. The block diagram of the receiver structure of 8 channel DWDM system is shown in Fig. 6.

Table 2: Parameter values of standard single mode fiber and dispersion compensation fiber

Parameters	SMF	DCF	Unit
Length	Variable	Variable	km
Attenuation	0.2	0.5	dB/km
Dispersion	17	-85	Psec/nm/km
Dispersion slop	0.075	-0.3	Psec/nm^2/k
PMD coefficient	0.2	0.2	Psec/km
Effective area	80	22	μm^2
Nonlinear refractive index, n2	26×10^{-21}	26×10^{-21}	W/m^2
Wave length	1550	1550	nm

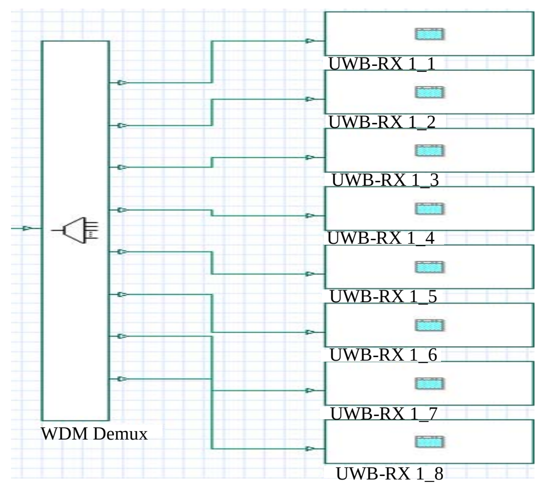

Fig. 6: Block diagram of the receiver part for 8 channel

Each block of the receiver is contain photo detector PIN, band pass filter and eye diagram. Use performance PIN photodiode as photo detector than Avalanche Photo Diode (APDs) because it sensitivity to shot noise and low cost. PIN photo diode provide better performance in wide bandwidth. The mixer output is filtered using low pass filter having a cut-off frequency (0.75*symbol rate) to speared the modulated data from the frequency carrier and to reduce the noise generated in the detection and amplification process. After that, eye diagram analyzer used to detect the signal. The parameter of channel demultiplexed is the same used in Table 1.

RESULTS AND DISCUSSION

In this research, study increase the bit rate of the transmitted data using DWDM technique after get the signal of UWB optically. Also has been processed the loss that occur in optical fiber by using DCF and choose the maximum length that get BER = 10^{-10}.

All optical UWB pulses: Optical UWB signal that contain monocycle pulse and doublet pulse are generate based on (XGM) in (SOA). Figure 3 shows the block

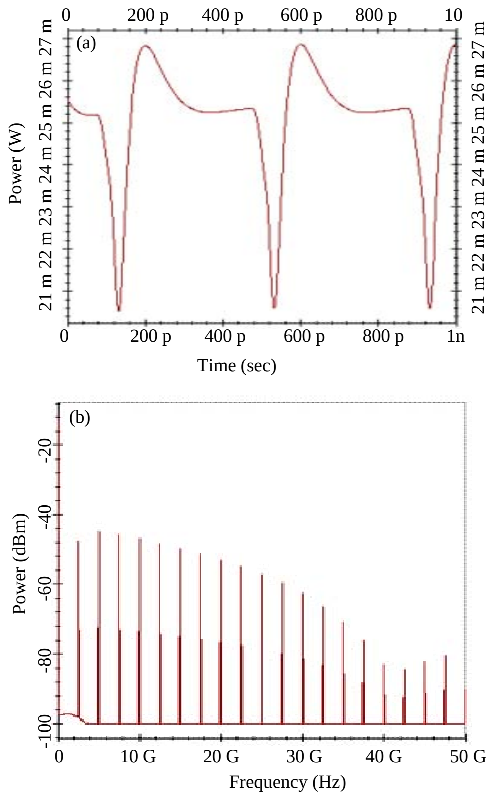

Fig. 7: a) UWB monocycle and b) RF spectrum

diagram of pulse generator. The simulation result has been taking the data rate 20 Gb/sec with bit sequence (0000000010000000). The width of the Gaussian pulse generator is 0.5 bit and choose the power of optical laser is (5 dBm) that matches the FCC definition with frequency equal (193.1 THz). The extinic ratio of the modulator is 30 dB and the injection current of the SOA is 0.07. A with group velocity 75×10^6 m/sec and 24 dB the attenuation of the optical attenuator. The frequency of optical filter is (193.1 THz) with 50 GHz bandwidth. The gain of photo diode is three with lionization ratio equal to 0.9. This parameter of this circuit acquired an UWB monocycle and doublet pulse with RF spectrum. Figure 7a and b show the UWB pulse and RF spectrum for monocycle pulse.

From Fig. 7 notice, the spectrum of the transmitter RF signal lies perfectly within FCC mask and the full width half maximum is 30 psec. Figure 8a and b illustrate the doublet pulse and RF spectrum.

From Fig. 8 of doublet pulses, notice the spectrum of the transmitter RF signal also satisfy FCC mask with full width half maximum is 21 psec.

Performance of DWDM: The simulation result are present for 10 Gb/sec signaling formats for OOK modulator. The length of the transmission link is 262.2 km that

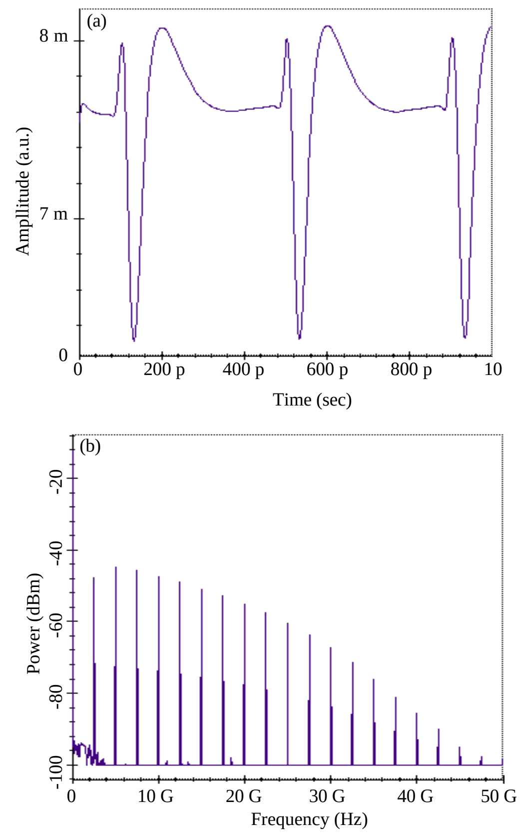

Fig. 8: a) UWB doublet and b) RF spectrum

corresponding the total length of SMF and DCF with optical filter with (400 and 800) GHz bandwidth for 8 and 16 channel, respectively to neglect unwanted signal that effect on the performance of the system. Take in the account, this length that chosen satisfy BER = 10^{-10} under single channel transmission. Figure 9 shows the optical spectrum analyzer and eye diagram of demultiplexer output corresponding to channel (1, 4, 8) for 8-DWDM.

From Fig. 9, notice that the degradation of signal was been happened in the middle of the channel due to the effect of nonlinearity fiber.

Figure 10 represent the optical spectrum analyzer and eye diagram of the output of demultiplexer corresponding to channel (1, 8, 16) for 16-DWDM.

Table 3 correspondes for BER in the simulated UWB signal based (8-16) DWDM system for OOK modulation format.

In this research, to study the performance of this system, measure of degradation is introduce to describe the normalized Bit Error Rate (BER_n). The Measure of Degradation (MOD) is define as:

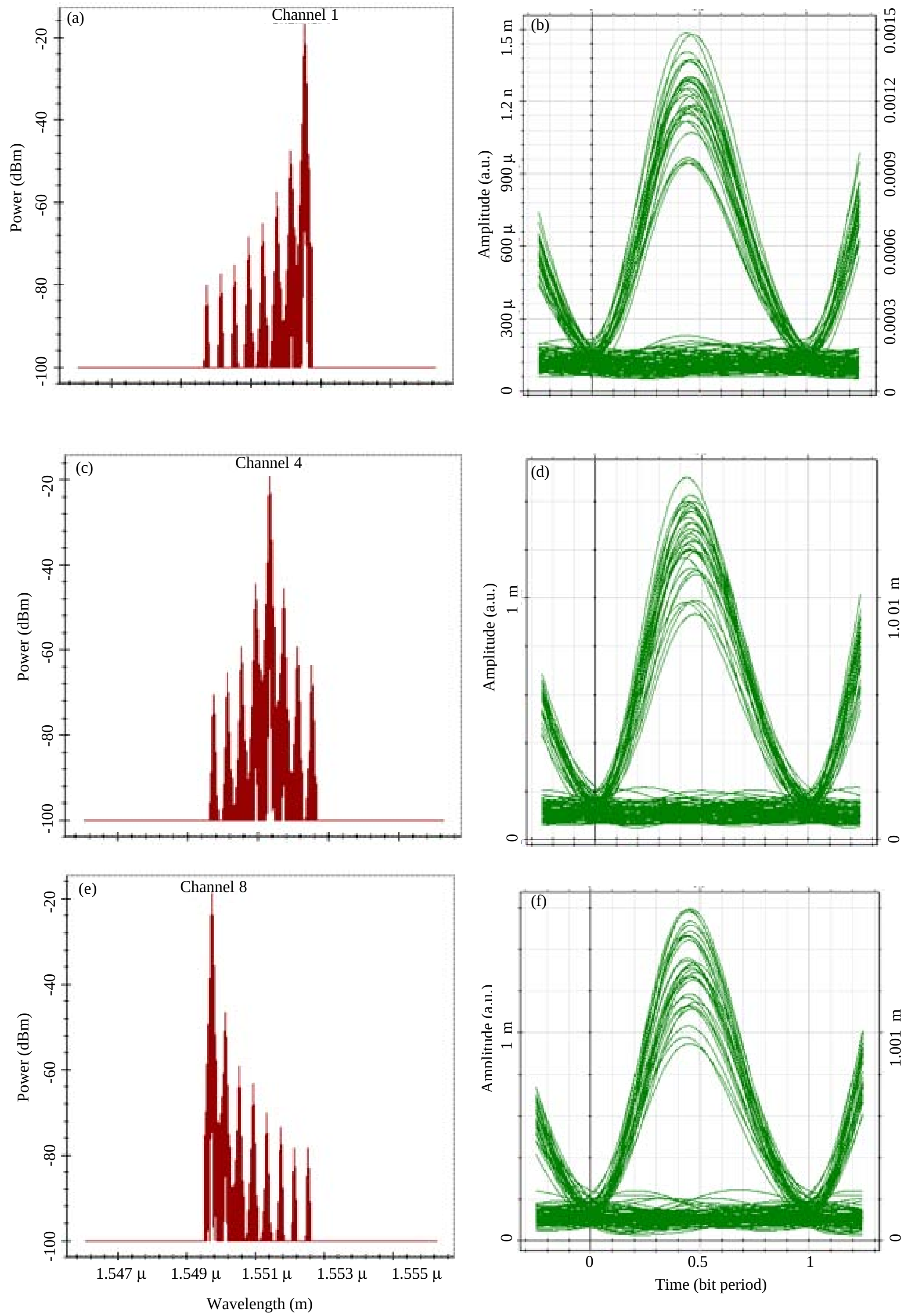

Fig. 9: Optical spectrum and eye diagram output for 8 channel DWDM: a) Optical spectrum analyzer for channel 1; b) Eye diagram output for channel 1; c) Optical spectrum analyzer for channel 4; d) Eye diagram output for channel 4; e) Optical spectrum analyzer for channel 8; f) Eye diagram output for channel 8

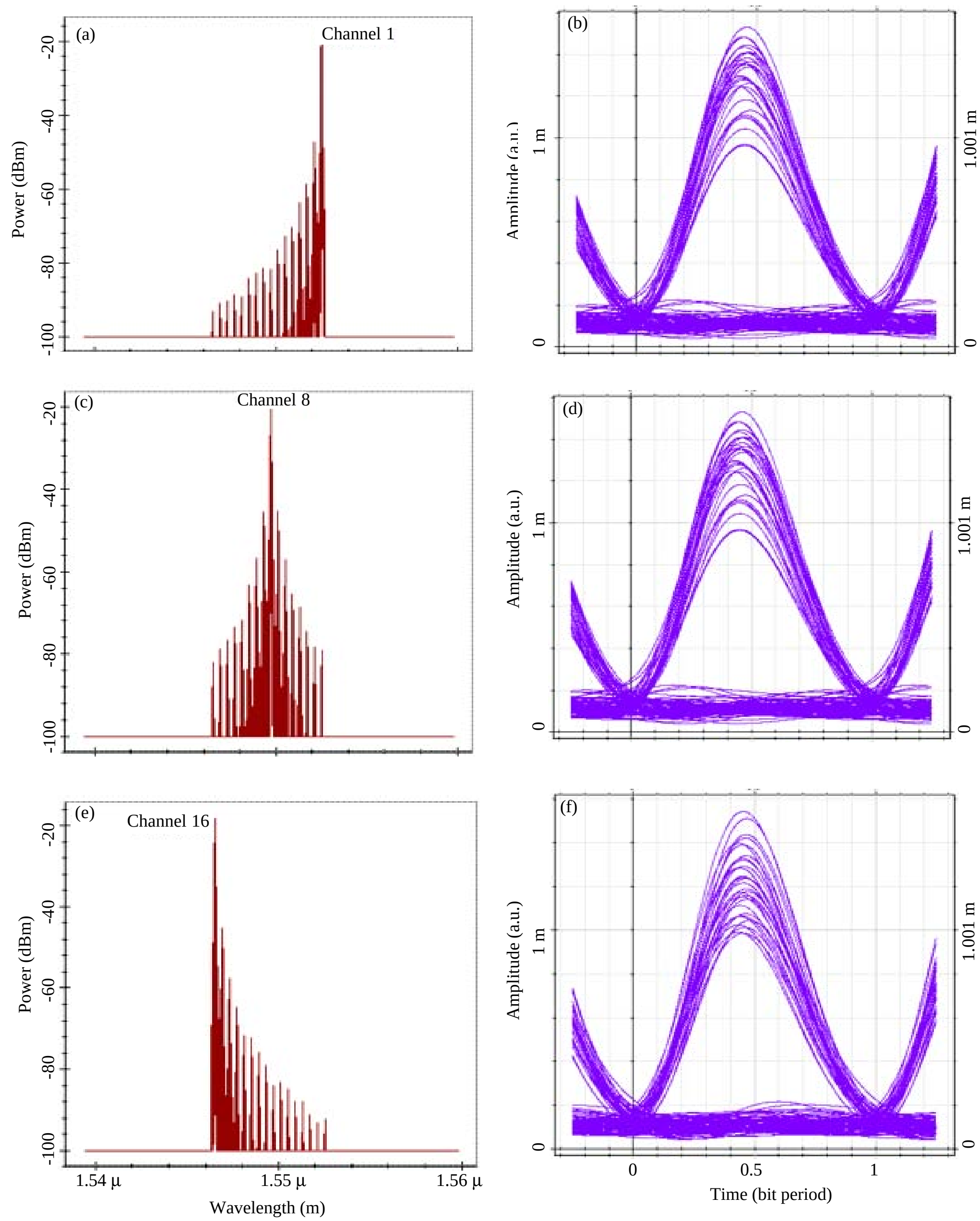

Fig. 10: Optical spectrum and eye diagram output for 16 channel DWDM: a) Optical spectrum analyzer for channel 1; b) Eye diagram output for channel 1; c) Optical spectrum analyzer for channel 8; d) Eye diagram output for channel 8; e) Optical spectrum analyzer for channel 16; f) Eye diagram output for channel 16

Table 3: BER for all optical UWB signal for 8 and 16 DWDM

Type of DWDM	Number of channel	BER
8 DWDM	1	2.54e-8
	4	6..47e-7
	8	5.56e-8
16 DWDM	1	1.27e-8
	8	1.18e-6
	16	6.69e-7

$$\text{MOD} = \log(\text{BER}_n) \quad (9)$$

Where:

$$\text{BER}_n = \frac{\text{BER}_{RC}}{\text{BER}_S} \quad (10)$$

Where BER_{RC} represent the received BER of each channel and BERs represent the BER identical to single

Table 4: Measure of degradation for 8 and 16 DWDM

Type of DWDM	Number of channel	Measure of degradation
8 DWDM	1	0.44
	4	1.85
	8	0.79
16 DWDM	1	0.9
	8	2.11
	16	1.86

channel. If MOD equal to zero that mean BER = 1 and this represent that the DWDM system insert not any power penalty compared with the single channel while if MOD more than zero, that means the performance of the received channel is degraded compared with the single channel.

For 8 DWDM, we calculated the MOD for three channel (i.e., for channel 1, 4, 8) and notice that the degradation of the signal is bigger in the channel 4 compared with another channel and equal to 1.85.

For 16 DWDM, we calculated the MOD for three channel (i.e., channel 1, 8, 16) and notice that the degradation of the signal of UWB is greater in the middle channel and equal to 2.11. Table 4 shows the BER measure degradation associated with (8-16) DWDM system for OOK modulation format.

From Table 4, it can conclusion that the BER performance is degraded in the DWDM system whether in 8 channel or 16 channel and this effect is more clear in 16 DWDM. The main reason that cause the degradation is fiber nonlinear optics and this nonlinearity represented by Four Wave Mixing (FWM) and cross Phase Modulation (XPM) that effect on the transmitter channel.

CONCLUSION

In this research, designed of all optical UWB signal interleaved to DWDM system was been investigated. In our research, we obtained FWHM for the all optically pulse generated is 30 psec for monocycle pulse shape and 21 psec in doublet pulse shape using OOK modulation technique.

The enhancement of the system was achieved at 10 Gb/sec DWDM technology with 8 and 16 channel at 50 GHz channel spacing where the increasing of system capacity reach to 80 and 160 Gb/sec for 262.2 km transmission link to get BER = 10^{-10} under single channel transmission. The BER performance is degraded in the DWDM system due to fiber non-linear optics that represented by FWM and XPM and the effect appearance clear in 16 channel.

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