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PERFORMANCE EVALUATION OF DUOBINARY TRANSMITTER FOR HIGH SPEED N×40GB/S TRANSMISSION OVER STANDARD SINGLE MODE FIBRE USING WAVELENGTH DIVISION MULTIPLEXING

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Abstract

In this paper, performance of Duobinary modulation format is investigated in Wavelength Division Multiplexing System for a next generation high data rate of 40 Gb/s per channel. The main objective is to simulate and review the optical spectra, efficiency and Bit Error Rate (BER) for standard single mode fibre with Duobinary modulation. With variation of fibre length from 90km to 270km and WDM channel capacity from 4 to 16, simulation shows impressive performance in BER, bandwidth reduction, spectral efficiency and channel capacity. But with increase of fiber length, BER starts to fall apart showing the incapability of the modulation over long haul transmission. Studying all the cases, "Duobiray" is considered to be a promising modulation technique for short distance transmission only. For long haul, it is incapable of performing efficiently. Lastly, further scope of research is discussed and future work has been recommended.

Keywords: Duobinary, EDFA, SMF, WDM, OptSym, BER, Performance Analysis.

1. Introduction

In the recent years, due to increase in data transmission rate, low system cost and higher bandwidth efficiency, notable achievements have been made in the field of optical fiber communication. Moreover, system capacity has also increased due to the increase in the data rate and reduced channel spacing [1, 2]. Recently, a number of studies [1, 2] shows that Wavelength division multiplexing (WDM) has the capacity to support high bandwidth data transmission. The new generation light wave system has facilitated higher data rate per channel (40 Gb/s and above) [3] and dense wavelength division multiplexing technique (DWDM). Furthermore, in long distance high bit-rate optical transmission, chromatic dispersion (CD), attenuation and non-linear effects are responsible for limiting transmission distance. Erbium-doped fiber amplifiers (EDFA) can balance the fiber [3-6].

The dispersion influence can be overcome by utilizing periodic dispersion compensation with the help of dispersion compensation fiber (DCF) [7]. In the early 90s of the last century, the most used modulation format was 'Intensity Modulation' or 'On-Off Keying', which has a data rate of ~10 Gb/s. Even though this modulation technique worked reasonably well in the last century is no longer suitable with the current increased data rate. Currently, data rate is increased to ~40, ~80 or ~100 Gb/s together with a narrow channel spacing of ~100 GHz [3-7] for which 'On-Off Keying' is no longer suitable modulation format for new generation communication.

To address these matters, a new modulation technique [4, 5] is needed which would require less bandwidth, capable of carrying multiple bits per symbol and transmit large amount of information. Moreover, this modulation format should also have less sensitivity to self-phase and cross phase effects and finally, less susceptible to noise. A modulation technique less vulnerable to noise can be considered as a major improvement over the currently available modulation techniques. A number of researches has been carried out [3-8] where the authors proposed different advanced modulation technique. Among them, the 'Duobinary' modulation format has been taken into consideration for its less susceptibility to dispersion as well as non- linearity. Its receiver and transmitter are cost effective and less complicated compared with other advanced formats such as 'Differential Binary Phase Shift Keying' (DBPSK) [6-8], 'Differential Quadrature Phase Shift Keying' (DQPSK) [9], '8DPSK'.

There are numerous researches on Duobinary modulation over different transmission channel along with different parameters. Li et al. [9] and Sun et al. [10] tried to maximize the power budgets by using Duobinary transmission systems based on 1.55-µm directly modulated lasers (DML) for optical access networks of 28 Gb/s per wavelength while skipping the use of optical amplifiers over 40-km long SSMF. Abbasi et al. [11] presented BER characteristics according to optical received power utilizing Duobinary direct modulation operated at 40 Gb/s over 2 km non-zero dispersion shifted fiber (NZ-DSF) with a dispersion coefficient of 4.5 ps/nm*km with wavelength 1.55 µm. Performance comparison between low-pass filter or delay-and-add circuit to produce 3-level electrical Duobinary signals over 45-km SSMF at 28-Gb/s is presented by Sun et al. [12] and they claim from their experimental results that low pass filter performs better than the delay-and-add circuit.

Zou et al. [13] proposed a novel external DSP 112-Gbps system for the first time with SFP form factor and Duobinary 4-PAM signalling where the nonlinear Volterra pre-equalizer works as compensation for non-linarites, can cover 10 km. They conclude that this promising system can greatly enhance the capacity of single slot line card and become a prominent candidate for next generation mobile back-haul and data-centre interconnection. Suhr et al. [14] also presented a novel approach by employing direct Duobinary aiming up to 10 km SMF with 56 Gbps total bit rate using direct detection which will responsible for reducing latency.

An impressive wavelength division multiplexed passive optical networks (TWDMPON) system, using 25-Gb/s Duobinary modulation is demonstrated over 20-km SSMF by Ye et al. [15]. Authors had experimental results for both upstream and downstream separately and manifest significant performance improvement. But a research gap has been observed in terms of specific comparison of the Duobinary technique with and without WDM both for long and short haul transmission for high data rate. This paper tries to fill up the gap observed in the research industry.

The main objective of the paper is to simulate Duobinary Modulation format in a wavelength division multiplexing system for a given data rate of ~40 gigabit per second. Both SMF and DCF were utilized in the transmission link and the calculation was made to get a fully dispersion compensated system. The contribution of this paper lies on investigation of performance factors of the optical system such as Bit Error Rate, Quality Factor for high-speed data transmission over single mode fibre with variation of WDM channel and fiber length for Duobinary transmitter.

2. Duobinary Modulation

Duobinary or Phase Shaped Binary Modulation format was carried out first in 1960’s by a person name Adam Lender. In intensity Modulation, ‘1’ and ‘0’ represent the switch on and off of a LASER source. After modulation, the electrical bit stream converts into optical signal and as a result the amplitude changes. On the contrary, in Duobinary modulation, there are 3 states of signal levels instead of two which are ‘0’, ‘1’ and ‘2’. Each symbol here is the addition of the current and previous state. If the current state is assumed to be ‘K_n’ and the previous state to be ‘Kn-1’, the formation of symbol levels are as follows (Table 1) [11-15]:

Table 1. Duobinary modulation states.

Current bit (K_n)	Previous Bit(K_{n-1})	State
1	1	2
1	0	1
0	1	1
0	0	0

The bias voltage can easily be changed in order to revalue the three levels to be 1, 0 and -1 instead of 2,1 and 0. The phase difference between the upper level and lower level is ~π. In a 'Duobinary' modulation format, if R bits are being transmitted per second, the bandwidth of the signal will be R/2, which is the 'Nyquist Rate' of a transmission making duo binary format to be bandwidth efficient twice of Non Return to Zero On-Off Keying (NRZ OOK).

3. Simulation Model

The designs and modelling were both constructed and simulated in the industrial level software OptSim [16]. 'CW Lorentzian Laser' was used as the optical source with the Centre Emission Wavelength of ~1550 nm. The power was fixed at ~0 dB. Two types of optical links were used which are SMF and DCF. For SMF the fiber attenuation was 0.2 dB per kilometer and the dispersion was fixed at '17 ps/nm/km'. Fiber non-linear coefficient was selected to be ~1.36811 l/w/k. For DCF the dispersion was fixed at '-100ps/nm/km' and the length was calculated in such a way where the total dispersion in a transmission to be 0 ps/nm. The EDFA used in the setup had gain of 30 dB and noise figure (NF) of 5 dB. Figure 1 represents the Duobinary transmitter set-up and transmission model in singe mode fibre using WDM.

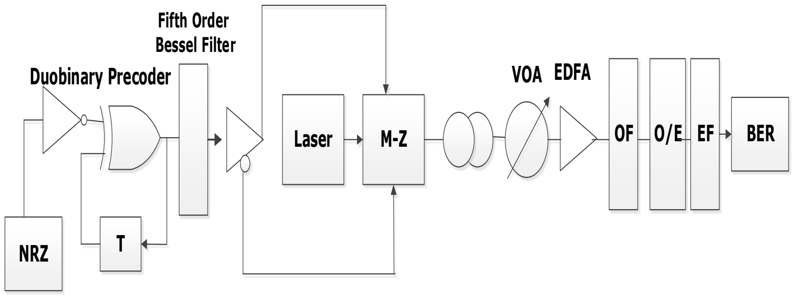


Fig. 1. Transmitter set-up of Duobinary modulation.

3.1. Transmitter and receiver complexity

Table 2 indicates the transmitter and receiver set-up elements for our simulation.

Table 2. Transmitter and receiver simulation set-up.

Modulation Format	Transmitter Complexity	Receiver Complexity
Duobinary	(a) 1 Dual Arm Mach Zehnder Modulator (b) Driver Amplifier for each modulation arm (c)Duobinary filter	1. Photodiode

3.2. Transmitter link

Transmission link comprises with a multiplexer and a Demultiplexer at the starting and end respectively (Fig. 2). In VBS, "Combiner" and "Splitter" had been used for multiplexer and Demultiplexer respectively. A "Fixed Gain EDFA Booster" was added after the combiner followed by "SMF" and "DCF". Inline amplifier was used to strengthen the signal after fiber span. A post amplifier was included after the loop followed by the splitter. The gain of all EDFA was fixed at 30 dB with a noise figure of 5 dB. The "Attenuator" was put into the circuit to kill the gain of the "Booster".

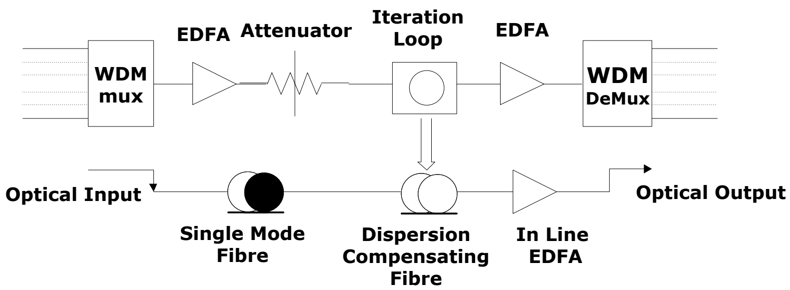


Fig. 2. Transmission link.

3.3. Simulation set-up

Following Fig. 3 is the 8 channel WDM simulation diagram built in Optsim for Duobinary modulation in Single Mode Fibre. Information in a form of random bit of streams was generated by Bit generator, which then went through Pulse Generator to form a square pulse. Next, it was passed through RZ and NRZ modulation schemes with the carrier laser wave. Thereafter it was sent to the fibre optics through WDM and after pre and post amplifying process, the optical signal would be received by the receiver consisting of a Demultiplxer, photodiode and filter. Simulation was done in order to test the optical system in Optsim. After implementing the design parameter, the performance parameter (Eye diagram and Bit Error Rate- BER) were evaluated to get the impairment parameter and the data was compared with the published values in order to get the suitable modulation format.

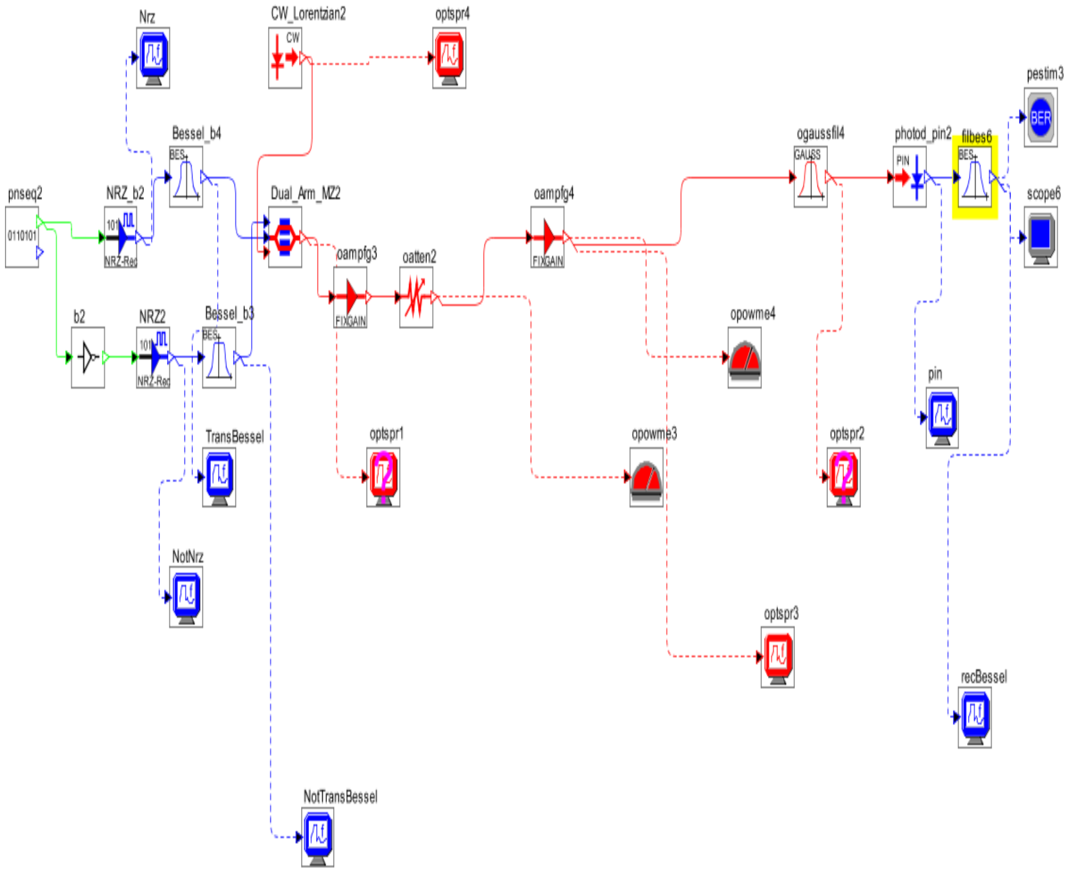


Fig. 3. Duobinary transmitter and receiver set-up in single mode fibre communication link.

3.4. Design parameters:

Table 3 states the design parameters used in our simulation

Table 3. Simulation parameters descriptions.

<table>
<tr><td colspan="2">Bit Rate</td><td>40 Gb/s</td></tr>
<tr><td colspan="2">Optical Source</td><td>CW Lorentzian LASER</td></tr>
<tr><td rowspan="2">Optical Link</td><td>SMF</td><td>Total length of SMF was divided into three stages- 90 km, 180 km and 270 km. Operating Wavelength: 155 0nm, Fiber loss: 0.2 (dB)/km. Fiber no-linear coefficient ~ 1.36811 1/w/k.</td></tr>
<tr><td>DCF</td><td>DCF introduces negative dispersion to the fiber in order to make the total dispersion in a transmission to be 0. '-100ps/nm/km' of dispersion was introduced to DCF. The calculated length of DCF for the compensation of dispersion is described as follows:
$$\text{Length of SMF(km)} = \frac{D_{SMF}}{\text{Dispersion Introduced by DCF}}$$
Here, D_{SMF} indicates the total dispersion introduced by SMF
<table><tr><td>SMF length</td><td>90 km</td><td>180 km</td><td>270 km</td></tr><tr><td>D_{SMF}</td><td>1530 ps/nm</td><td>3060 ps/nm</td><td>4590 ps/nm</td></tr><tr><td>Length of D_{SMF}</td><td>15.3 km</td><td>30.6 km</td><td>45.9 km</td></tr></table></td></tr>
<tr><td colspan="2">EDFA</td><td>"Flat Gain" EDFA was used throughout the entire period with a gain of 30 dB. "The Flat Noise Figure" was kept as 5 dB.</td></tr>
<tr><td colspan="3">Modulation format- Duobinary</td></tr>
</table>

4. Results and Discussion

Spectral Bandwidth (3 dB): From the above diagram provided by the Optical Spectral Analyzer, the bandwidth of 'Duobinary' optical spectra was found to be ~40 GHz (3 dB). In Fig. 4, the value was expressed in THz.

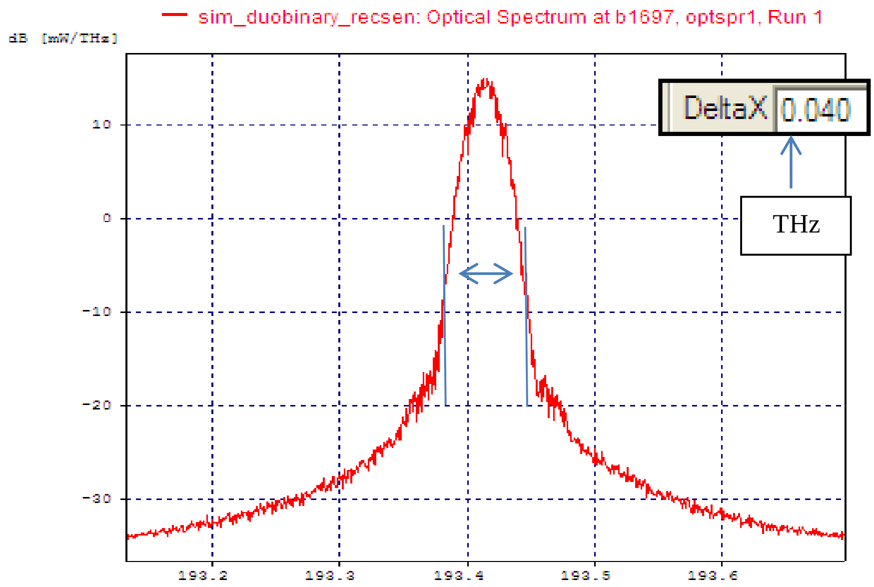


Fig. 4. Optical Spectrum for RZ-OOK (Bit Rate~ 40 Gb/s).

4.1. Spectral Efficiency

According to the formula of Spectral Efficiency [17]

$$Spectral\ Efficiency = \frac{Bit\ rate}{Spectral\ Bandwidth} \quad (1)$$

$$Spectral\ Efficiency_{Duobinary} = \frac{40}{40}\ \text{Bit/s/Hz} \sim 1\ \text{bit/s/Hz}$$

4.2. Filter Cut-off frequency

Receiver filter 3 dB frequency [17-19] = (0.75 x Spectral Bandwidth) (2)

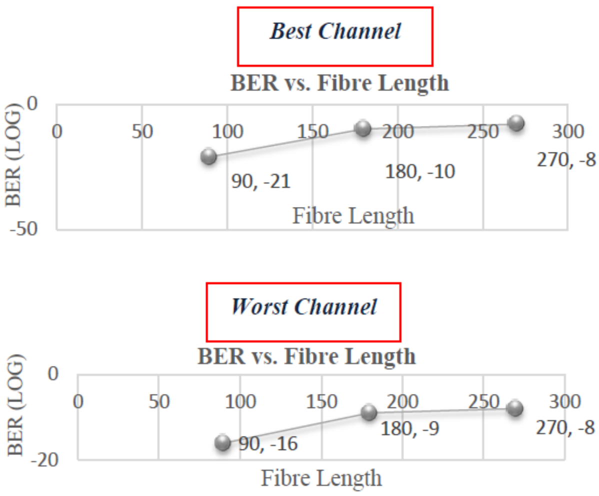
$$\text{Receiver Filter 3 dB frequency}_{\text{Duobinary}} = (0.75\ \times \text{Spectral Bandwidth})$$

$$= 30\ \text{GHz}$$

However, it was found that at the cut-off frequency of 28 GHz, the receiver filter was working properly. This 2 dB decrease of the filter bandwidth made 'Duobinary' to be superior to NRZ in terms of filter bandwidth.

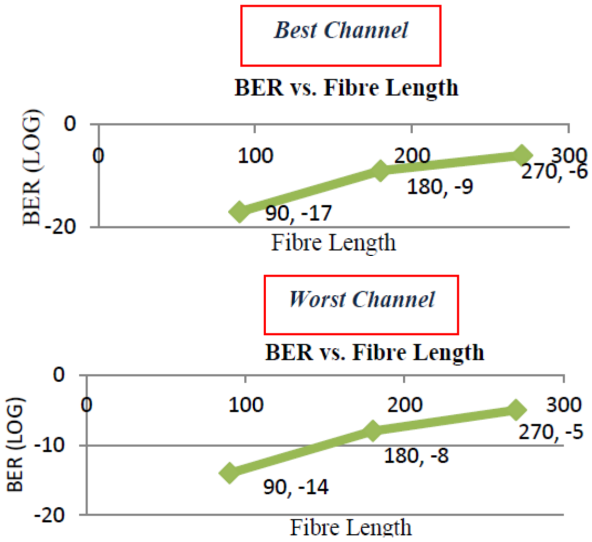
4.3. Bit Error Rate and Eye Diagram Analysis

Figures 5, 6 and 7 display the BER of the receiver side and Fig. 8 shows the "Eye Diagram" for 16 channels for each span (Best Channel). Key thing to notice here that with the increase of fiber length, BER decreased radically making it unsuitable for long distance transmission. On the other hand, it showed solid performance with the increasing number of channels. Unlike the previous two modulation formats, BER did not fall down significantly with the increase of channel number.



Fibre Length (km)	Worst channel (BER)	Best Channel (BER)
90	10^{-16}	10^{-21}
180	10^{-9}	10^{-10}
270	10^{-8}	10^{-8}

Fig. 5. BER Values of 4 Channel Duobinary (Bit rate~ 40 Gb/s).



Fibre Length (km)	Worst channel (BER)	Best Channel (BER)
90	10^{-14}	10^{-17}
180	10^{-8}	10^{-9}
270	10^{-5}	10^{-6}

Fig. 6. BER Values of 8 Channel Duobinary (Bit rate~ 40 Gb/s).

Fibre Length (km)	Worst channel (BER)	Best Channel (BER)
90	10^{-8}	10^{-12}
180	10^{-6}	10^{-7}
270	10^{-4}	10^{-5}

Fig. 7. BER Values of 16 Channel Duobinary (Bit rate~ 40 Gb/s).

'Duobinary' showed outstanding performance in terms of bandwidth reduction. Li et al. [20] worked with the same configuration with RZ-OOK and measured its spectra as 160 GHz. Comparing to RZ-OOK, its optical spectra squeezed to one fourth of 'RZ-OOK'. It also had spectral efficiency of approximately ~1bit/s/Hz where as traditional modulation format "Return to Zero OOK" showed approximately ~0.25 bit/s/Hz with the same configuration [20].

In 4 Channel WDM, while varying the fiber length, it was interesting to observe that although "Duobinary" started off with solid performance of BER ~10-21 for 90 km, the performance radically fell apart with increase of fiber span. For 180 km of SMF, the BER of it increased by ~10-11 whereas for 270 km it showed a value of ~ 10-8. Analysing '8 Channel WDM', in spite of having an excellent BER of ~10-17 at the beginning, "Duobinary" again fell apart along the way with the increase of fiber length. For a length of 180km, BER of it increased to 10-9 and for a length of 270 km, it ended up having a poor BER of ~10-6. Lastly, while investigating '16 Channel WDM', "Duobinary" as usual started with a low BER of ~10-12 (for 90km), with the increase of fiber span it went high dramatically as it ended up with poor BER of ~10-5. Studying all the cases, "Duobiray" however starting off with a low BER every time but failed to maintain it and finally ending up having poor BER as the fiber length increased every time for all the 3 different number of channels.

Therefore, "Duobinary" was decided not to be suitable long haul transmission. Analysing the WDM Channel Capacity, it can be concluded that "Duobinary" gave good performance in terms of "WDM Channel Capacity" as it managed to show low BER despite of the increase in channel number. Referring to the work of Li et al. [20], Malekmohammadi et al. [21, 22], and Khan et al. [23], traditional modulation format RZ-OOK showed poor performance in terms WDM for; all the 3 different number of channels as the BER increased from 10-9 to 10-6 for a channel number of 4 and 16 respectively. However, in our case, while increasing the fiber span, "Duobinary" fell apart and was no longer able to provide better BER performance

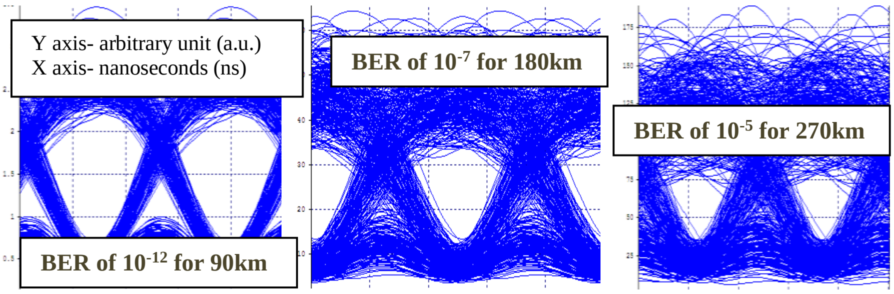


Fig. 8. Eye diagrams for 16 Channel WDM of Duobinary modulation format.

5. Conclusion

The objective of this paper was to observe the performance of the Duobinary Modulation for a WDM network with a data rate of ~40 Gb/s. and from the result, it is evident that the objectives of this experiment were successfully achieved. Even though Duobinary showed some outstanding performance in bandwidth reduction, spectral efficiency and channel capacity, it showed poor performance with the increase of fiber length. There are several other ways for the implementation of Duobinary. Our experiment and results recommends future research on advanced techniques such as RZ-Duobinary and CSRZ-Duobinary (Carrier suppressed Return to Zero) for better BER and higher spectral efficiency. This paper also recommends to conduct simulation of WDM based standard mode fibre by varying polarization mode dispersion, refractive index and some other factors, which were fixed or deactivated throughout this paper.

Nomenclatures

D_{SMF}	Dispersion in Single Mode Fibre

Abbreviations

BER	Bit Error Rate
CD	Chromatic Dispersion
DBPSK	Differential Binary Phase Shift Keying
DCF	Dispersion Compensating Fibre
DPSK	Differential Phase Shift Keying
DQPSK	Differential Quadrature Phase Shift Keying
DWDM	Densed WDM
EDFA	Erbium-doped fiber amplifiers
IM	Intensity Modulation
NRZ	Non Return to Zero
OOK	On-OFF Keying
RZ	Return to Zero
SMF	Single Mode Fibre
WDM	Wavelength Division Multiplexing

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