A MULTILEVEL MULTIPLEXING TECHNIQUE FOR HIGH SPEED FIBER OPTIC COMMUNICATION SYSTEMS

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Amin Malekmohammadi[1] and Ahmad Fauzi Abas[2]
[1]*Department of Electrical and Electronic Engineering, Faculty of Engineering,*
The University of Nottingham, (Malaysia Campus), Jalan Broga, 43500 Semenyih, Selangor
[2]*Department of Computer and Communication Systems Engineering,*
Universiti Putra Malaysia, 43400 Serdang, Selangor
E-mail: [1]amin.maleknottingham.edu.my, [2]fauzi@eng.upm.edu.my

ABSTRACT

In order to explore the potential of optical multilevel signaling for high speed optical fiber networks, a novel multilevel multiplexing technique is demonstrated. Three users, each with data rates of 10 Gb/s were successfully multiplexed and transmitted over a single WDM channel, which can offer a possible transmission rate of 30 Gb/s per WDM channel. The performance of the proposed technique is examined, with comparison to 30 Gb/s Time Division Multiplexing (TDM). Based on the simulation results back-to-back receiver sensitivity of -29.2 dBm and -33.5 with OSNR of 22.5 dB and 18.3dB was achieved for the worst and best uses respectively, together with the chromatic dispersion tolerance ranging from 207 ps/nm to 276 ps/nm. A comparison with conventional TDM technique shows a clear advantage of the proposed technique.

Keywords: *Dispersion Tolerance, Multiploxing, Optical Communication*

1.0 INTRODUCTION

The advances in data communication and information technology allow tremendous amounts of data to be transferred through the networks. From one year to another, the required network capacity increases exponentially, which shows that Tb/s capacity is not far from reality.

Many kind of multiplexing such as Wavelength Division Multiplexing (WDM) technology, Time Division Multiplexing has recently shown their potential to support high bandwidth data transfer [1; 2; 3]. Time Division Multiplexing is a digital process that can be applied when the transmission capacity of a medium is larger than the transmitting and receiving devices data rate. In such case, multiple transmissions can occupy a single link by subdividing it into several slots.

Optical multilevel signaling is one of the candidates for these advanced signaling techniques used for future high speed long-distance optical networks [4]. It can reduce the optical signal bandwidth to pack more signal channels in a single optical fiber by WDM technique, and improve the signal transmission performance such as chromatic dispersion tolerance. For example, four-level phase modulation, namely, differential quadrature phase-shift keying (DQPSK) [5] was thoroughly studied to realise ultrahigh capacity WDM networks. Obviously, there are other methods employed to provide more transmission capacity such as quadrature signaling and spectrum coding [6] so that more than one channel can be transmitted in a single wavelength. However these methods are not economical and are difficult to realise.

The proposed technique which is called Absolute Polar Duty Cycle Division Multiplexing (AP-DCDM) is a new multiplexing technique which uses return to zero duty cycle and bipolar signaling. In this technique, subsequent users at the multiplexer input have opposite polarity, which results in a unique multilevel pattern at the output of the multiplexer. As a result of bipolar signaling, the increment of the multiplexed signal amplitude with reference to the number of user is reduced, therefore, improving the receiver sensitivity, which is the main limiting issue in multilevel signaling. In this paper, we demonstrate that AP-DCDM is able to support multi-users transmission per WDM channel at acceptable performance.

2.0 WORKING PRINCIPLE

AP-DCDM is a multiplexing technique that uses bipolar signal with different duty cycle to differentiate the channels or users. In this technique, each user transmits bit '0' with zero volts and for the case of bit one, the odd users transmit '$+A$' volts while the even users transmit '$-A$' volts. Based on the linear distribution of duty cycle, the i^{th} multiplexing user transmits bit 1 within T_i second, which is

$$T_i = i \times \left(\frac{T_s}{n+1} \right) \qquad (1)$$

Where T_s is the symbol duration and n is the number of users. Therefore, different users share the communication medium to transmit in the same time period and at the same carrier wavelength, but with different duty cycles. The unique duty cycle for each channel helps to regenerate data at the receiver. Figure 1 illustrates the signal multiplexing process for three users system. In Figure 1(a), 8 possible combinations of users' data are shown which is referred to as Case 1 to Case 8. Figures 1(b), (c) and (d) show the duty cycle distribution of the three user system, where 25%, 50% and 75% duty cycle are used to represent User1 (U25), User2 (U50) and User3 (U75) respectively. Noting that the second user has opposite polarity to the first user, and similarly, the third user has opposite polarity relative to the second user. Based on the 2^n possible bits combination in Figure 1(a), each of these combinations produces unique symbols with both positive and negative polarity [Figure 1(e)]. The process ends by taking the absolute value of the signal in Figure 1(e) to produce absolute polar DCDM signal. Figure 1(f) shows the absolute polar signal for the eight possible combinations of bits for three users. Having the knowledge about this uniqueness at the receiver side, the original data for each user can be recovered.

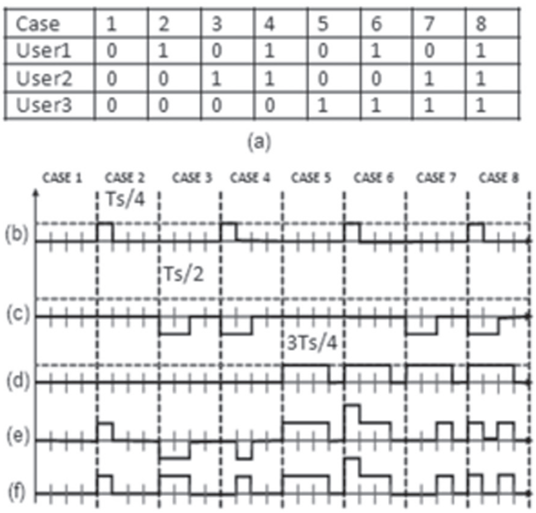

Figure 1: (a) eight possible combination of bits for three users, (b) U25 data stream, (c) U50 data stream, (d) U75 data stream, (e) bipolar multiplexed signal and (f) absolute polar multiplexed signal

3.0 SIMULATION SETUP

Figure 2 (a) shows the simulation setup. Three users each at 10 Gb/s with PRBS 2^{10}-1 are carved with three electrical RZ pulse carver at 25%, 50% and 75% duty cycle respectively. The voltages for all users at the multiplexer input are identical. All users' data are multiplexed via a power combiner (electrical adder) resulting in a bipolar signal. Subsequently, the absolute circuit is used to produce an absolute polar signal.

The signals are modulated onto a laser diode (LD) signal which operates at 1550 nm wavelength using a Mach-Zehnder Modulator (MZM). The eye diagram of the modulator output is shown in Figure 2(b). At the receiver side, the optical signal is detected by a photodiode and passed through a low-pass filter (LPF) and Clock-and-Data-Recovery (CDR) unit. The Gaussian low-pass filter is set at 0.75 of the null-to-null bandwidth, which is determined by the smallest duty cycle, to eliminating the photodiode noises.

In the CDR unit, the received signal is fed into the sampling circuit. The samples are taken at three sampling points of S_1, S_2 and S_3 at the first three slots in every symbol [Figure 2(b)]. Outputs of the sampling circuit are fed into the decision and regeneration unit. In this unit, the sampled values are compared against two threshold values, thr_1 and thr_2 [Figure 2(b)] and the decision is performed based on the operations shown in Tables I, II and III. These tables contain the regeneration rules that the data recovery unit uses to regenerate original data for each user, which are based on the multiplexed signals shown in Figure 1(f). For example, for U25, binary 0 is regenerated when sampling values at S_1 and S_2 are less than thr_1 (Table I rule 1) or values at S_1 is in between thr_1 and thr_2 while values in S_2 are greater than thr_1 (Table 1 rule 2). Binary 1 is regenerated when sampled amplitude at S_1 is in between thr_1 and thr_2, while amplitude at S_2 is less than thr1 (Table I rule 3) or values in S_1 is less than thr1 and values in S_2 are greater than thr_1 (Table 1 rule 4) or values in S_1 and S_2 are greater than thr_1 and thr_2 respectively (Table 1 rule 5).

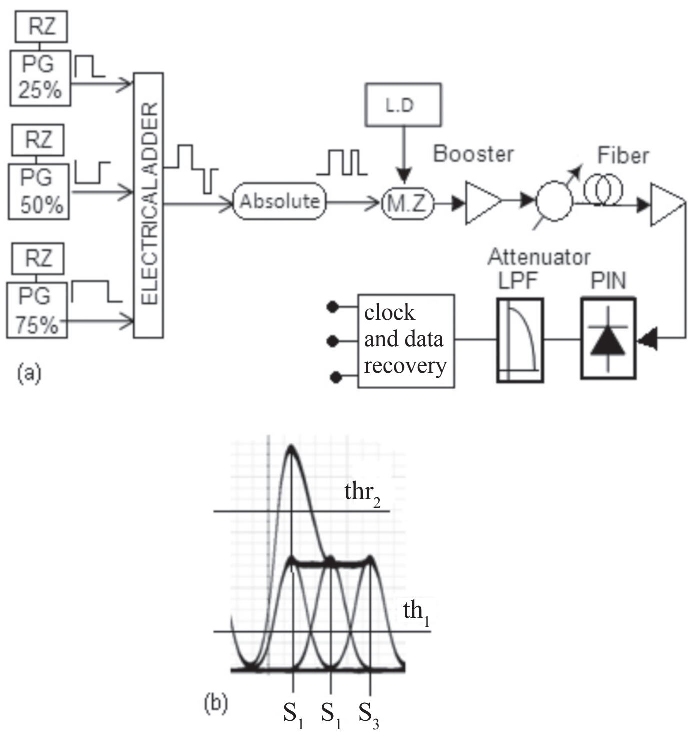

Figure 2: (a) AP-DCDM simulation setup for multiplexing three users, (b) Transmitted eye diagram including sampling points and threshold values

Table 1: Data recovery rules for U25

No	Rules				Case
1	if $(S_1 < thr_1)$	and	$(S_2 < thr_1)$	then U25 = 0	Case: 1, 7
2	if $(thr_1 \leq S_1 < thr_2)$	and	$(S_2 \geq thr_1)$	then U25 = 0	Case: 3, 5
3	if $(thr_1 \leq S_1 < thr_2)$	and	$(S_2 < thr_1)$	then U25 = 1	Case: 2, 8
4	if $(S_1 < thr_1)$	and	$(S_2 \geq thr_1)$	then U25 = 1	Case: 4
5	if $(S_1 \geq thr_2)$	and	$(S_2 \geq thr_1)$	then U25 = 1	Case: 6

Table 2: Data recovery rules for U50

No	Rules	Case
1	if $(S_2 \geq thr_1)$ and $(S_3 < thr_1)$ then U50 = 1	Case: 3,4
2	if $(S_2 < thr_1)$ and $(S_3 \geq thr_1)$ then U50 = 1	Case: 7,8
3	if $(S_2 < thr_1)$ and $(S_3 < thr_1)$ then U50 = 0	Case: 1,2
4	if $(S_2 \geq thr_1)$ and $(S_3 \geq thr_1)$ then U50 = 0	Case: 5,6

Table 3: Data recovery rules for U75

No	Rules	Case
1	if $(S_3 < thr_1)$ then U75 = 0	Case: 1, 2, 3, 4
2	if $(S_3 \geq thr_1)$ then U75 = 1	Case: 5, 6, 7, 8

4.0 RESULTS AND DISCUSSION

Figure 3 shows the back-to-back pre-amplified receiver sensitivity for the three users, 30 Gb/s (3 x 10 Gb/s) AP-DCDM system. They are compared against conventional 30 Gb/s TDM. In AP-DCDM system, the three users show different performance. At bit-error-rate (BER) of 10^{-9}, U25 has the receiver sensitivity of around -29.2 dBm with OSNR of 22.5 dB, while U50 and U75 have the same receiver sensitivity of -33.5 dBm with OSNR of 18.3 dB. In comparison to 30 Gb/s TDM, our proposed system shows better sensitivity for U50 and U75, in the order of 1 dB.

Figure 4 shows the effect of chromatic dispersion to the performance of 30 Gb/s conventional TDM and 30 Gb/s TDM over AP-DCDM. Using AP-DCDM, all users show almost similar behavior of positive and negative chromatic dispersions. U25 and U50 have the same ability to tolerate chromatic dispersion of ±103.5 ps/nm while U75 has the dispersion tolerance of ±138 ps/nm at BER of 10-9. For the 30 Gb/s conventional TDM, dispersion tolerance is around ±86.5 ps/nm. This result shows that 30 Gb/s TDM over AP-DCDM is more robust to dispersion in comparison with 30 Gb/s conventional TDM. This is because of smaller spectral width of the former technique. The simulated time-averaged eye diagrams at various dispersions are shown in Figure 5.

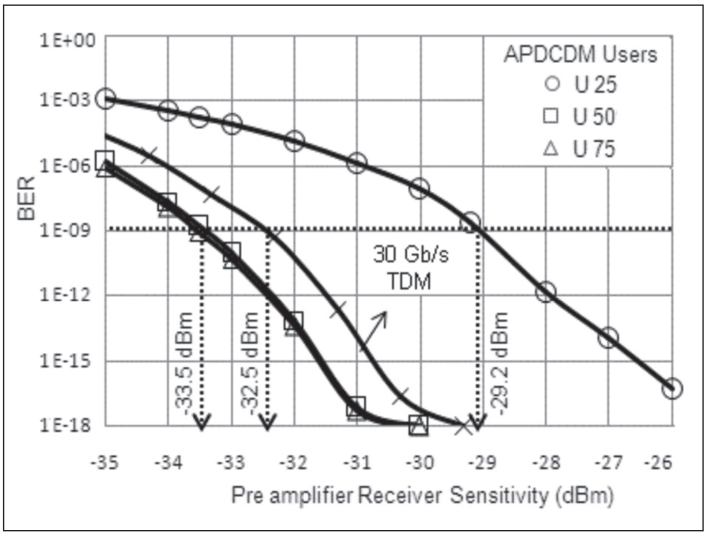

Figure 3: Pre-amplified receiver sensitivity for three channels 30 Gb/s TDM over AP-DCDM and 30 Gb/s conventional TDM

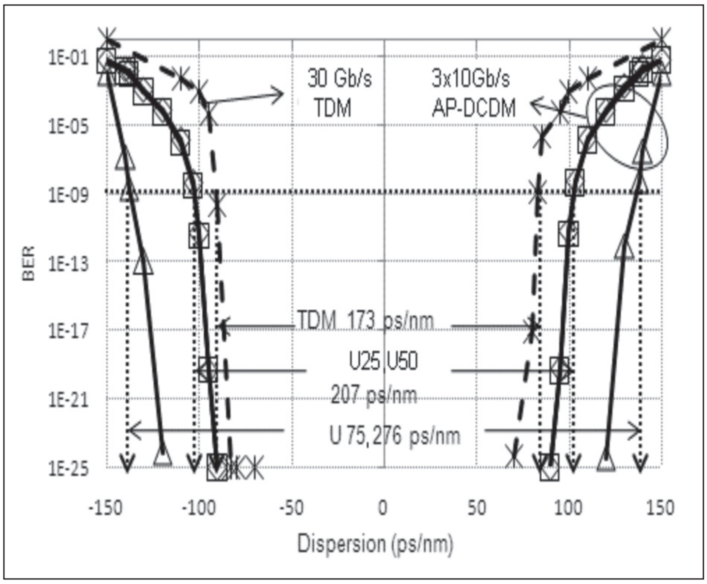

Figure 4: Chromatic dispersion tolerance comparison between AP-DCDM and TDM at the same transmission power

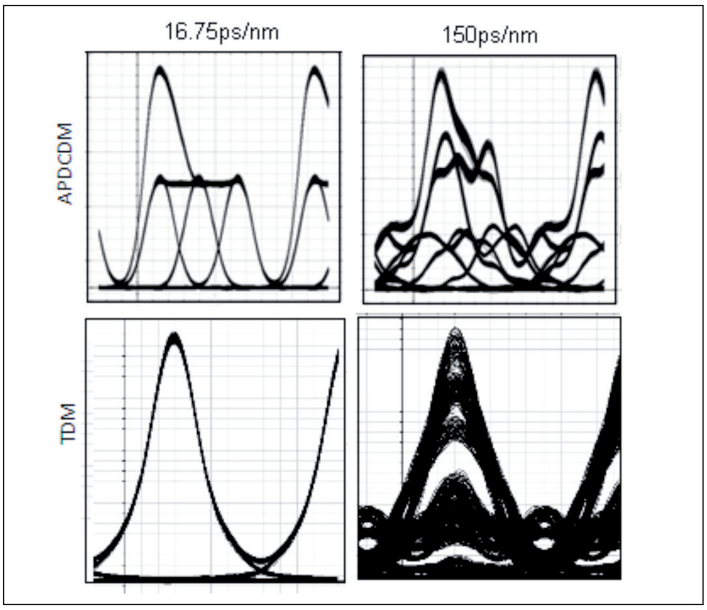

Figure 5: Eye diagrams for TDM over AP-DCDM and conventional TDM at different dispersions

5.0 CONCLUSIONS

The principle of the AP-DCDM technique and the proof of its viability are discussed. Using this electrical multiplexing or demultiplexing technique, more than two users can be carried over a WDM channel. Therefore, the capacity utilisation of the WDM channels can be increased tremendously at tolerable penalty. Performance of AP-DCDM was examined with back-to-back receiver sensitivity, OSNR and chromatic dispersion tolerance. AP-DCDM system shows better sensitivity for U50 and U75, in the order of 1 dB in comparison to conventional TDM at 30 Gb/s. For chromatic dispersion, AP-DCDM shows higher dispersion tolerance in comparison to conventional TDM at the same capacity. The results confirm the ability of AP-DCDM to become an alternative multiplexing technique in optical fiber communications. ■

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PROFILES

DR AMIN MALEKMOHAMMADI is a member of IEEE, IEEE-LEOS and Optical Society of America (OSA), received his PhD degree in Computer System Engineering (Optical Communications) at Universiti Putra Malaysia, 2009. Currently he is working at the Department of Electrical and Electronic Engineering, University of Nottingham as an assistant professor. He is also with the Georgia Green Institute for Electromagnetic Research, University of Nottingham, UK as an associate member. He has authored and co-authored 40 technical papers which include journals articles and conference proceedings. He has filed 3 patents for his inventions and scientific works.

IR. ASSOC. PROF. DR AHMAD FAUZI ABAS obtain his Doctor of Engineering (Dr-Ing.) from University of Paderborn, Germany in 2006. Since then, he joined the Department of Computer and Communication Systems Engineering, Faculty of Engineering, Universiti Putra Malaysia as a lecturer. Currently, he is an Associate Professor in the same department, where he leads the Photonic and Fiber Optics Systems Research Working Group. He has authored and co-authored around 100 technical papers, which include journal articles and conference proceeding. His research interest are in optical communications, devices and sensors.