A Multiplexing Technique for Improving Dispersion Tolerance in Optical Communication Systems

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ABSTRACT

We propose a multiplexing technique that uses different Polar Return-to-Zero duty cycles to differentiate the channels for enhancing dispersion limited transmission in high speed fiber optic communications. It is demonstrated that the spectral width occupied by 30 Gb/s TDM is 120 GHz whereas, this value can be reduced to around 80 GHz and 70 GHz for 30 Gb/s TDM over 3 and 6 channels of the proposed system respectively. By increasing the number of channels at the same aggregated bitrate, the spectral width of this technique is reduced which leads to better tolerance to chromatic dispersion. Comparison against other techniques such as M-ary-RZ and M-ary-NRZ shows clear advantage of proposed technique

Keywords: Multiplexing, chromatic dispersion, spectral width

1- INTRODUCTION

Fueled by the seemingly inexhaustible human appetite for more bandwidth per user and, by the new requirements that are far less predictable than they have been before, the bandwidth utilization moved ever forward. Before the invention of optical fiber the transmission medium has always been the scarcest resource [1]. Closely coupled to the generation, processing, and storage of digital information is the need for data transport, ranging from short data buses all the way to long-haul transport networks. In an effort to make the most efficient use of resource, various technologies have been developed so that multiple users can be supported in the same transmission medium. This concept is called "multiplexing". The most commonly used multiplexing techniques in communication systems are time division multiplexing (TDM) [2]. Increasing the bandwidth utilization can be realized by either using more wavelength division multiplexing (WDM) channels or increasing the bit rate of Time Division Multiplexing (TDM) signals [3]. In general, ideal modulation format for long-haul, high speed WDM transmission links is the one with compact spectrum and good dispersion tolerance [4]. Many researchers have for some times, examined multilevel signaling, e.g. AM-PSK polybinary, M-ary, Amplitude-Shift-Keying (ASK) and polyquaternary as a way of improving the system performance against Chromatic Dispersion (CD) and Polarization mode dispersion (PMD) due to its reduced spectral occupancy [5]. The main issues in those techniques are degradation in receiver sensitivity due to the increased number of levels and the signal dependence on signal-spontaneous beat noise [6].

Absolute Polar Duty Cycle Division Multiplexing (AP-DCDM) was reported for the first time in [7] and [8] as an alternative multiplexing technique for wireless and optical communications respectively. AP-DCDM is a multiplexing technique which uses Return-to-Zero duty cycle and bipolar signaling to differentiate the channels at the receiver. In this technique, subsequence users at the multiplexer input have opposite polarity, which results in a unique multilevel pattern at the output of the multiplexer. Having the knowledge of this uniqueness at the receiver side, the original data for each user can be recovered [7, 8].

In this paper, AP-DCDM is modeled and characterized in dispersive optical transmission medium. It is also verified that AP-DCDM is able to support the transmission of many users per WDM channel; therefore, the capacity of the WDM channels can be increased tremendously at tolerable penalty. The results are compared against conventional TDM technique, M-ary-Return-to-Zero (RZ) and M-ary-Non-Return-to-Zero (NRZ) techniques. It is the interest of this paper to show that by using AP-DCDM, increasing the number of channels at the same aggregate bitrate, produces the signal spectral width that is relatively less than conventional technique, which leads towards an improved tolerance to chromatic dispersion. In this paper the performance evaluation of the systems is based on Bit Error Rate (BER), as described in [9, 10].

2- WORKING PRINCIPLE

As reported in [7-9], AP-DCDM is based on having each channel modulated with a unique polar RZ duty cycle. In this technique each user transmits bit '0' with zero volts and for the case of bit one, the odd users transmit with '+*A*' volts and the even users transmitted with '–*A*' volts. Based on the linear distribution of duty cycle, the i^{th} multiplexing user transmits bit 1 within *Ti* second, which is

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

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 same carrier wavelength but with different duty cycles. The unique duty cycle for each channel helps to regenerate the data at the receiver side [7, 10].

3- SETUP

Fig. 1 (a) shows the simulation setup. Data1, Data2 and Data3, 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 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 Fig. 1 (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 0.65 of the null-to-null bandwidth, which is determined by the smallest duty cycle, for eliminating the photodiode noises. In the CDR unit, the received signal is fed into the sampling circuit. Samples are taken at three sampling points of S_1, S_2 and S_3 at the first three slots in every symbol (Fig 1(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 (Fig. 1(b)) and the decision is performed based on the regeneration rules as described in [8, 9].

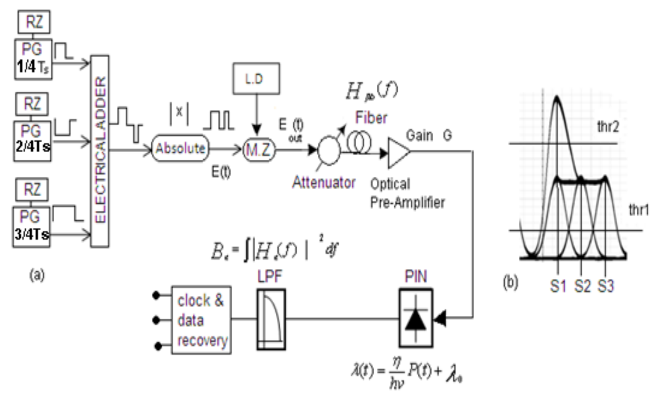
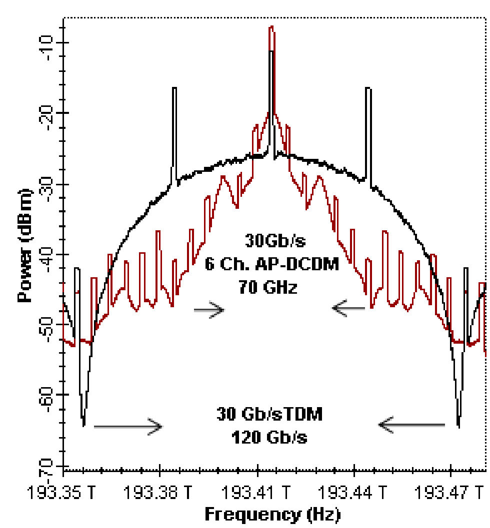


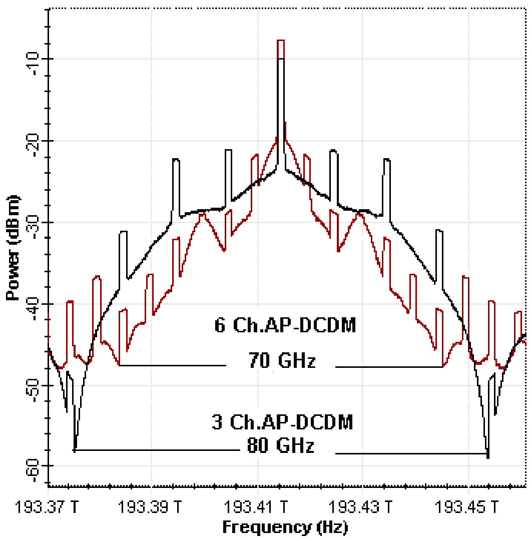
Fig.1 Simulation Setup

4- RESULT AND DISCUSSION

Comparing the optical spectral width at the same aggregate bit rate between TDM without AP-DCDM and TDM over 3 and 6 channels AP-DCDM, shows a great spectral width reduction for the later technique. As shown in Fig. 2 the spectral width of 30 Gb/s TDM without AP-DCDM is around 120 GHz, whereas, this value is reduced to 80 GHz (around 33.33%) and 70 GHz (around 41.66 %) in TDM over 3 and 6 channels AP-DCDM respectively. This is because AP-DCDM divides the symbol to *n+1* slots (considering 1 slot for guard band), where *n* is the number of users. Thus it requires a null-to-null spectral width of 2 × [(*n+1*) × single channel bit rate], whereas; TDM using RZ requires 2 × (2 × aggregated bit rate). This amount of saving in the spectral width is a significant achievement, which leads to better tolerance to chromatic dispersion.



(a)



(b)

Fig. 2 Spectral Width Comparison at 30 Gb/s between (a) 6 Channels AP-DCDM and TDM (b) 6channels APDCDM and 3 channels AP-DCDM

Fig. 3 shows the effect of chromatic dispersion to the performance of 30 Gb/s conventional TDM and 30 Gb/s TDM over 3 x 10 Gb/s AP-DCDM. Using AP-DCDM, all users show almost similar behavior of positive and negative chromatic dispersions. User with 25 % duty cycle (U25) and user with 50% duty cycle (U50) have the same ability to tolerate chromatic dispersion of ±103.5 ps/nm while user with 75% duty cycle (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 to 30 Gb/s conventional TDM. This is because of smaller spectral width of the former technique.

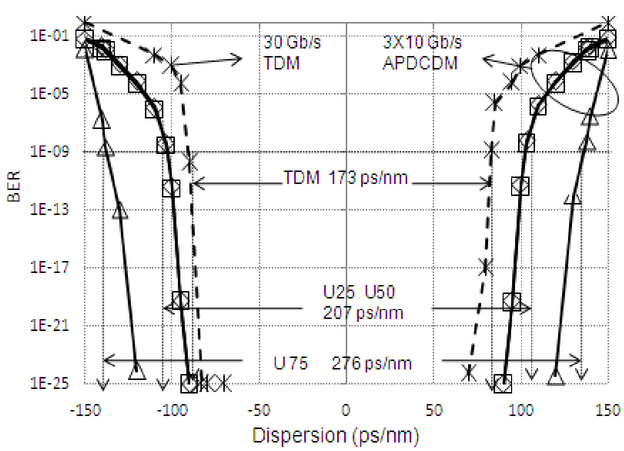


Fig. 3 Chromatic dispersion tolerance comparison between 3 x 10 Gb/s AP-DCDM and 30 Gb/s TDM at the same transmission power

Fig. 4 shows the dependence of dispersion tolerance to the number of channels in AP-DCDM, at the same aggregated bit rate of 30 Gb/s and the BER of 10^{-9}. By increasing the number of channels from 3 to 6 the dispersion tolerance increased from 207 ps/nm to 236 ps/nm. This is due to 10 GHz (around 12.5%) spectral width reduction in 6 channels AP-DCDM in comparison to 3 channels AP-DCDM.

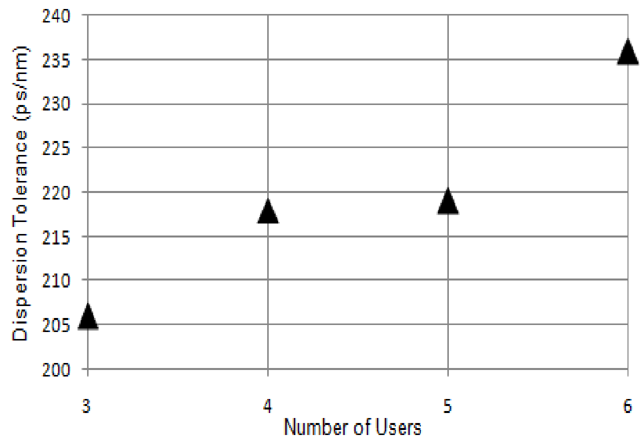


Fig. 4 Dispersion tolerance against the number of channels

Fig. 5 (a) shows the dependence of the receiver sensitivity on the amount of system dispersion at BER of 10^{-9} for three channels, operating at the same speed of 10 Gb/s, which can offer a possible transmission of 30 Gb/s per WDM channel for different modulation techniques. First we observe that On-Off-Keying (OOK) produces better performance for a small amount of dispersion. As the amount of system dispersion increases the performance of OOK degrades faster than 8-ary and AP-DCDM. This is mainly due to the spread of the energy of the binary pulses into adjacent bit slots. As illustrated in Fig. 5 (a) AP-DCDM shows better performance as compared to 8-ary RZ and NRZ at all dispersion points. Examples of eye diagrams corresponds to BER of 10^{-9} for AP-DCDM, OOK, 8-ary RZ and 8-ary NRZ and at two dispersion values (250 ps/nm and 1000 ps/nm) are shown in Fig. 5 (b). At 1000 ps/nm, huge time jitter and eye closure are observed for conventional OOK. This problem is not experienced by AP-DCDM and M-ary. For conventional OOK, high received power is required to maintain the performance as shown in Fig. 5 (a).

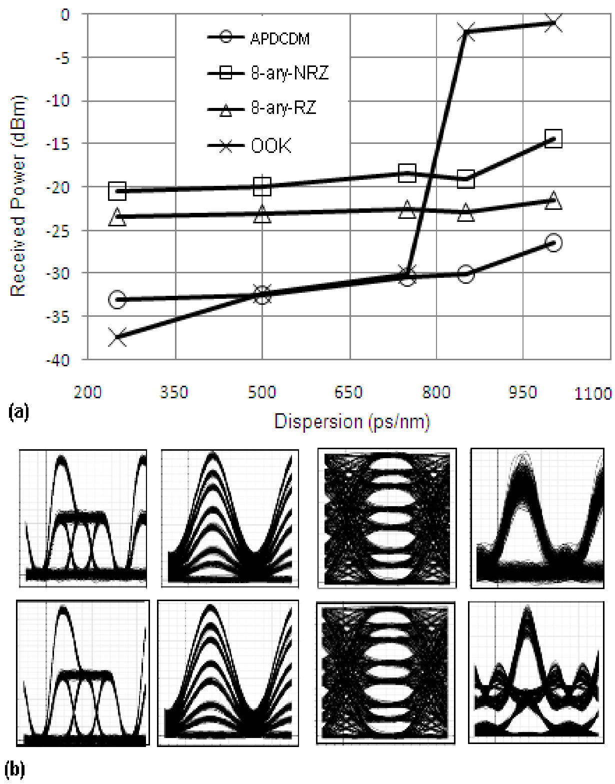


Fig.5 (a) Receiver sensitivity against system dispersion(30 Gb/s) (b) Eye diagrams at BER of 10^{-9} for 30 Gb/s systems at system dispersion of 250 ps/nm (top) and 1000 ps/nm (bottom), for AP-DCDM, 8-ary RZ, 8-ary NRZ and TDM (left to right)

5- CONCLUSION

Performance of AP-DCDM against Chromatic Dispersion was evaluated. The numerical results confirm that using this electrical multiplexing/demultiplexing technique, more than two users can be carried over the same WDM channel. Consequently, the capacity utilization of the WDM channels can be increased tremendously; which is achieved at a lower spectral width and better dispersion tolerance in comparison to conventional TDM technique. It is also verified that by increasing the number of users the spectral width of the AP-DCDM system is reduced which leads to better robustness to chromatic dispersion. For the high system dispersion level, AP-DCDM requires less power as compared to OOK and M-ary techniques.

6- REFERENCES

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