Proceedings of IEEE 2008 6th National Conference on Telecommunication Technologies and
IEEE 2008 2nd Malaysia Conference on Photonics, 26-27 August 2008, Putrajaya, Malaysia

Analysis of the Transmission Performance of Optical Signals based on Duty Cycle Division Multiplexing (DCDM)

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Abstract—**In this paper, duty cycle division multiplexing (DCDM) is proposed as an alternative multiplexing technique. It can be applied in any communication systems, although the focus in this paper is in optical fiber communications. In this paper, we examine 3 channels each operating at 10 Gbps modulation rate over a single optical carrier. The performance comparison is made against 30 Gbps RZ transmitted pulses, time domain multiplexed (TDM). The results show that at a fixed transmission power, DCDM can support longer distance than that with RZ TDM technique. Also, the results show that RZ-TDM pulses require 35.5 dB more SNR to support the same distance as that for DCDM.**

Keywords-multiplexing; duty cycle; optical communication

I. Introduction

Multiplexing is one of the key issues in increasing the capacity of communication systems. It allows different users to share the available carrier bandwidth and communicate simultaneously [1-3]. The existing multiplexing techniques include; time division multiplexing (TDM) [4-6], frequency or wavelength division multiplexing (FDM) [1, 7] or (WDM) [8, 9], and code division multiplexing (CDM) [10-12].

TDM is widely used in communication systems today [13-15]. However, in high speed communication systems, TDM requires very high-speed electronic element for multiplexing and de-multiplexing resulting in high cost [6, 16-18]. On the other hand, clock recovery is another issue in high speed communication systems [19-22]. Therefore, many investigations have been done to design and develop reliable and cost-effective clock recovery modules for high speed communication systems [19-23].

Realizing these problems, duty cycle division multiplexing (DCDM) is proposed in this paper as an alternative multiplexing technique. This technique allows users to share communication media utilizing different duty cycles. The proposed technique also has an inherent property of multiple amplitude transitions in a slot period which allows for better clock recovery (however, the elaboration is beyond the scope of this paper).

The purpose of this paper is to introduce the new multiplexing technique. In section II, the basic functions and characteristics of DCDM are explained. The simulation study and results are discussed in the subsequent sections followed by a conclusion.

II. Basic Function of DCDM

The DCDM technique is based on the unipolar return to zero (RZ) line code. In this technique, each user transmits a bit of 0 with zero volts within T_s second where T_s is symbol duration, and bit 1 is transmitted with +*A* volts with a duration less than T_s seconds. This duration defines for i^{th} user as

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

where n represents the number of multiplexing users. For example, for multiplexing 3 users, the 1st, 2nd and 3rd user uses duration of $3T_s/4$, $2T_s/4$ and $T_s/4$ respectively to transmit bit 1s. Fig. 1(b), (c) and (d) show signals with 25, 50 and 75% duty cycle respectively based on the bits represented in Fig. 1(a). Thus, different users can share communication media to transmit simultaneously utilizing different duty cycles. These signals can be multiplexed by adding them up using an electrical adder or electrical combiner, as the multiplexed signals shown in Fig. 1(e).

Based on the number of multiplexing users, there are 2^n possible combinations of bits for n users. In the multiplexed signal, each of these combinations produces a unique symbol. Fig. 1(a) shows the 8 possible bit combinations for the case of 3 users. The multiplexed symbols for the 8 cases are presented in Fig. 1(e). By having the knowledge about this uniqueness, at the receiver side, the original data for each user can be easily distinguished and recovered by taking 1 sample per slot (except the last slot which considered as guard band).

	Cases	1	2	3	4	5	6	7	8
(a)	User 25%	0	1	0	1	0	1	0	1
	User 50%	0	0	1	1	0	0	1	1
	User 75%	0	0	0	0	1	1	1	1

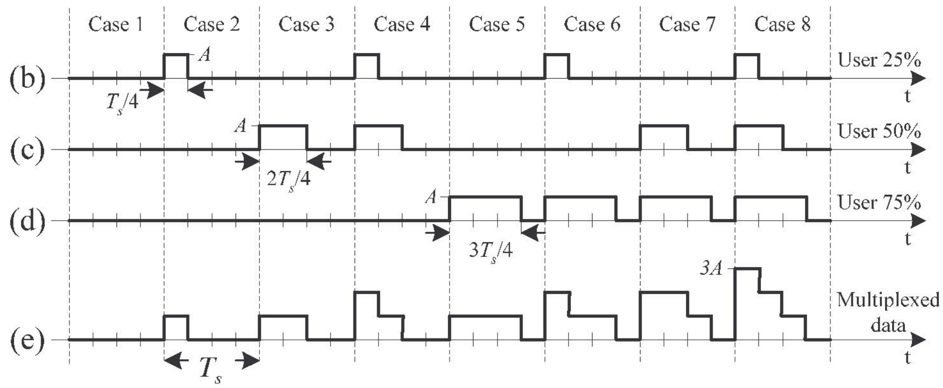

Fig. 1. (a) Eight possible combination of bits for 3 users, (b), (c) and (d) signal of the user with 25, 50 and 75% duty cycle respectively, (e) multiplexed signal of those 3 users.

This technique allows for automatic bit error detection and correction, based on the sequence of sampled amplitudes per symbol duration. For the case of multiplexing *n* users, if only one sample per slot is taken, then, the 1st sample (taken from the 1st slot), has $n+1$ possible levels, the 2nd sample (taken from the 2nd slot), has *n* possible levels, and the n^{th} sample (taken from the n^{th} slot), has only 2 possible levels (0 or *A* volts).

III. SIMULATION STUDY

A. *Simulation Setup*

Fig. 2 shows the simulation setup used in this study. Data of three users, Data1, Data2 and Data3, each with 10 Gbps modulated with three RZ modulators set at 75, 50 and 25% duty cycle respectively. The signals are multiplexed with an electrical combiner and then modulated with a single light source utilizing an amplitude modulator (AM). Standard single mode fiber is used as communication medium. At the receiver side, the optical signal is detected by a photodiode and passed through a low pass filter and clock and data recovery circuit. The Gaussian low pass filter is set at 0.75 of the maximum signal bandwidth for eliminating the photodiode noises.

B. *Simulation Results*

In this study we have tested three different parameters of DCDM system and compare them with 50%-RZ transmitted pulses. Bit error rate (BER) is measured versus the system's signal-to-noise ratio (SNR) by exchanging attenuator with the optical fiber in Fig.2. In the next, we used standard single mode fiber to see how the BER changes over different fiber lengths. In the last we have tested the SNR versus different fiber length at BER of 1e-9.

Fig. 3 shows the BER versus SNR of the proposed system for all the three channels. All the three users have almost similar SNR at different BERs. Overall, the minimum SNR required for the DCDM users to get BER of 1e-9 is 21.5 dB. For comparison, we have tested a 30 Gbps 50%-RZ modulated signal with TDM technique. Results (Fig. 3) shows that, RZ coding requires around 7.2 dB less SNR to achieve the same BER. This means that the effect of noise on the DCDM system is more than on the RZ pulses. However, although DCDM has worse SNR, but it requires less bandwidth than RZ. The maximum bandwidth of the DCDM is 4 times the single user bit rate whereas it is 6 times the RZ pulses. We expected the SNR of DCDM gets closer to RZ coding by applying this amount of bandwidth on DCDM channels.

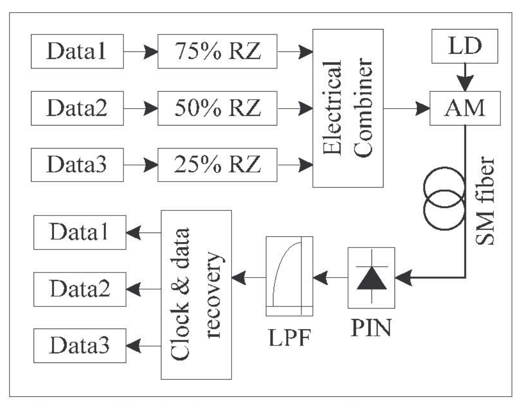

Fig. 2. DCDM simulation setup for multiplexing 3 users.

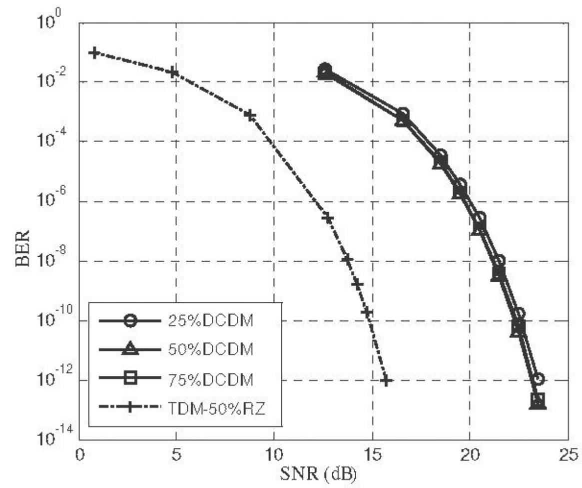

Fig. 3. BER versus SNR.

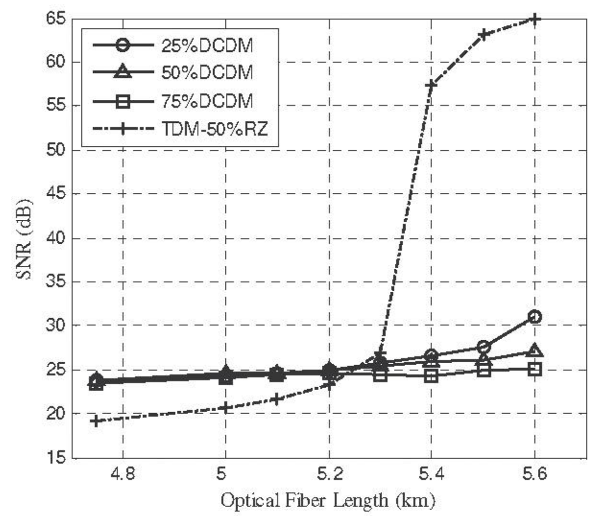

Fig. 5. SNR versus optical fiber length at BER of 1e-9.

Fig. 4 shows the BER versus fiber length. Three DCDM users perform differently over different fiber lengths. User with 75% duty cycle has much better performance than the other two users, while, user with 50% duty cycle is better than the one with 25% duty cycle. In comparison, all the DCDM users perform better than the RZ transmitted pulses. This means that the DCDM channels are less sensitive to the dispersion effects compared to the RZ pulses.

Fig. 5 shows the relationship between SNR and fiber length to achieve the BER of 1e-9. Based on the results, as the fiber length increases, the discrepancy of SNR for the different DCDM users is larger. Users with 75% and 25% duty cycles require the least and the most SNR for transmitting the same distance, respectively. Comparing these results with RZ signals show that, SNR of RZ coding increased very fast by a small increase in fiber length. RZ coding requires a significantly larger amount of SNR to support the same distance that DCDM can. For example, at a 5.5 km fiber length, there are around 35.5 dB difference between RZ coding and the worst user in DCDM. This result shows how the RZ coding signal is sensitive to dispersion effects.

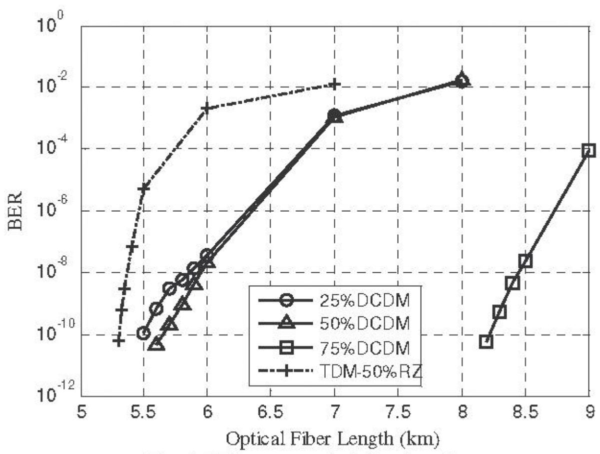

Fig. 4. BER versus optical fiber length.

IV. CONCLUSION

The principle of the DCDM technique has been discussed in this paper. Performance of DCDM was examined with SNR and fiber length. In SNR, DCDM channels require 7.2 dB more SNR than that RZ pulses for the same performance. Note that, DCDM requires less bandwidth than that RZ coding. We also showed that, at the same transmitted power, DCDM can transmit 30 Gbps data over longer distance in compare to RZ coding. RZ transmitted pulses requires 35.5 dB more SNR to transmit the same distance as DCDM sent. Based on the results we conclude that the DCDM performs better than the RZ coding in a non-zero dispersion system. Results confirm that DCDM can become an alternative multiplexing technique in optical fiber communications. This system allows channel multiplexing and demultiplexing to be performed in the electrical domain. Also, it requires only one decision system and regeneration circuit for all users. It is important to note that other advantages such as better clock recovery and error detection and correction benefiting from the inherent properties of this technique are not yet being considered in this report.

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