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Duty Cycle Division Multiplexing (DCDM)

A New Electrical Multiplexing Technique for High Speed Optical Communication Systems

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Abstract—**A new multiplexing technique based on duty cycle division is proposed, thus the name Duty Cycle Division Multiplexing (DCDM). DCDM can be applied in both electrical and optical domains, for wired and wireless systems. The new technique allows for more efficient use of time slots as well as the spectrum, taking advantage of both the conventional TDM and FDM. In this paper, three channels operating at the same speed of 10 Gbps per channel are multiplexed in the electrical domain. The performance comparison is made against 3×10 Gbps TDM, and the experimental simulation results show that the DCDM system can support higher bit rate than TDM and also, it is less sensitive to the chromatic dispersion effect.**

Keywords-multiplexing; duty cycle; optical communication

I. INTRODUCTION

Multiplexing is the key issue to increase the capacity of communication systems. It allows different users to share the available carrier bandwidth and communicate simultaneously [1]. In existing systems, the medium is normally shared based on time slot (TDM) [2, 3], carrier frequency (FDM/WDM) [4-6] or spectrum coding (CDM) [7, 8]. The goals of all multiplexing techniques are to support as many users at as high speed and at the lowest cost possible. Shannon's Law states that the highest obtainable error-free data speed, is a function of the bandwidth and the signal-to-noise ratio [9]. In communication systems, medium impairment factors, coding schemes, and architecture of modulation formats and multiplexing techniques are the favorite targets of investigations towards achieving the Shannon's limit [9]. Researchers in [10] and [11] implement Error Correction Code in order to achieve performance close to Shannon limit. At the same time, enhancement on multicarrier modulation systems would also bring us closer to Shannon limit [12]. In this paper we introduce a novel multiplexing technique, which is based on RZ duty cycles, thus Duty-cycle Division Multiplexing (DCDM), which can be used to achieve the performance as close as possible to Shannon's limit. This technique can be implemented in both wireless and wireline communication systems; for any types of carriers; RF, microwave and optical. In this paper, DCDM technique is implemented in an optical communication link with a setup as shown in Fig.1. Although the setup uses only a single wavelength channel, the system can be easily duplicated for other wavelengths to represent a WDM system. However, this is only relevant when the maximum number of DCDM channels per user has been reached, while a larger bandwidth is still required.

Obviously, there are other methods employed to provide more transmission capacity such as optical polarization based multiplexing [13], quadrature signaling [13] and spectrum coding [14] so that more than one channel can be transmitted in a single wavelength. However, these methods are not economical and are difficult to realize. In this paper we introduce for the first time to our knowledge a novel multiplexing technique based on RZ duty cycles, which allows signal multiplexing and demultiplexing to be performed economically in the electrical domain. Also, it requires only one decision system and regenerator for all uses. By using return-to-zero (RZ) modulation format and simple amplitude modulation (AM), the capacity of 30 Gbps per channel is achieved with –15.8 dBm receiver sensitivity. This achievement shows that DCDM can become a potential alternative to increase the transmission capacity tremendously.

II. WORKING PRINCIPLE

DCDM is based on having each channel modulated with a unique RZ duty-cycle. The multiplexing process can be done utilizing an electrical combiner or adder. The electrical adder adds up signals from different channels, each is assigned with a different duty cycle. A single light source is then modulated by the multiplexed signal using an amplitude modulator (AM). For multiplexing n number of users, the first channel is modulated with duty cycle of nT_1, the second user with a duty cycle of $T_2 = (n-1)T_1 / n$ and the third user with a duty cycle of $T_3 = (n-2)T_1 / n$ and so on. All channels are synchronized and transmitted at the same timeslot but within the specified duty cycle. The resulting bitstream is a multilevel signal, which is formed by the superposition of signals from different channels. Each time slot is divided into a number of sub-slots which is one count more than the number of channels (n+1 slots). The sub-slot duration follows the duty cycle used for T_n. Provided that channels are synchronized at the beginning of the timeslot, all channels may have signal components within the first sub-slot, resulting a maximum possible number of levels in the first slot given by $L = n+1$ where n is the number of channels. For the second sub-slot, all channels may have signal components except for the last (n^{th}) channel which is assigned the shortest duty cycle, hence, giving a maximum possible number of levels of n. For the third slot all channels may have signal components except the n^{th} and the $(n-1)^{th}$ channel and so on. Within each time slot, if the i^{th} channel sends logic "1", the level at the $(i+1)^{th}$ sub-slot is always one level lower than the i^{th} sub-slot (Fig. 1). This property is utilized by the receiver to demultiplex the channels. The receiver compares the amplitude levels at each i^{th} and $(i+1)^{th}$ sub-slot with n reference thresholds within each time slot. According to the thresholds value, if the level at the i^{th} sub-slot is higher than the $(i+1)^{th}$ sub-slot, then the i^{th} channel sent "1", and if the level is equal to $(i+1)^{th}$, then the i^{th} channel sent "0".

III. Simulation Setup

Fig. 1 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 or adder and then are used to modulate a wavelength carrier from a single light source utilizing an AM module. Examples of multiplexed signal are shown in Fig. 1. As shown in the figure, inside every 0.1 ns slot (1 symbol duration), multi-level stair-case patterned signal is produced depending on the bit sequence of each user. This multilevel signal is the key element that enables the signal demultiplexing in the electrical domain at the receiver. At the receiver, the optical signal is detected by a PIN photodiode and passed through a clock and data recovery circuit. In this unit, a sampler takes one sample per slot except the last slot which is considered as guard band. A decision system then performs based on the following operations. (In the following rules, S_i represents voltage of the sampling point i = 1, 2 and 3 and thr1 to 3 are three threshold values.)

Rules for User25% (U25%):

1) If $(S_1 < thr_1)$ & $(S_2 < thr_1)$, then U25%=0
2) If $(thr_1 \le S_1 < thr_2)$ & $(thr_1 \le S_2 < thr_2)$, then U25%=0
3) If $(thr_2 \le S_1 < thr_3)$ & $(S_2 \ge thr_2)$, then U25%=0
4) If $(thr_1 \le S_1 < thr_2)$ & $(S_2 < thr_1)$, then U25%=1
3) If $(thr_2 \le S_1 < thr_3)$ & $(thr_1 \le S_2 < thr_2)$, then U25%=1
5) If $(S_1 \ge thr_3)$ & $(S_2 \ge thr_2)$, then U25%=1

Rules for User50% (U50%):

1) If $(S_2 < thr_1)$ & $(S_3 < thr_1)$, then U50%=0
2) If $(thr_1 \le S_2 < thr_2)$ & $(S_3 \ge thr_1)$, then U50%=0
3) If $(thr_1 \le S_2 < thr_2)$ & $(S_3 < thr_1)$, then U50%=1
4) If $(S_2 \ge thr_2)$ & $(S_3 \ge thr_1)$, then U50%=1

Rules for User75% (U75%):

1) If $(S_3 < thr_1)$, then U75%=0
2) If $(S_3 \ge thr_1)$, then U75%=1

IV. Result and Discussion

Three parameters of system level testing such as back-to-back receiver sensitivity, chromatic dispersion (CD) and system bit rate have been simulated in this study. Fig.2 shows the receiver sensitivity of the proposed system for all the three channels. For a fair comparison, the same data used for 3 DCDM users, have also been multiplexed using time division multiplexing (TDM) with the same launch power. As the RZ pulses are reported as the more robust coding technique in nonlinear effect [15, 16] and polarization mode dispersion [17], 50%RZ is used for 3 TDM users. In general, the receiver sensitivity of all users in DCDM system at BER of 1e-9 is around -15.8 dBm. In comparison to TDM channels, whose receiver sensitivity is around –19.5 dBm, DCDM has about 3.7 dB worse. This is just to show that DCDM is more affected by noises. However, although DCDM has worse receiver sensitivity, it requires less bandwidth than TDM, which makes it less affected by dispersion as shown subsequently. Dispersion is more influential detrimental factor for high speed transmissions. The maximum bandwidth of the DCDM is 4 times the single user bit rate whereas it is 6 times the single user bit rate for TDM. We expected the receiver sensitivity of the two multiplexing technique get closer by applying this amount of bandwidth on DCDM channels.

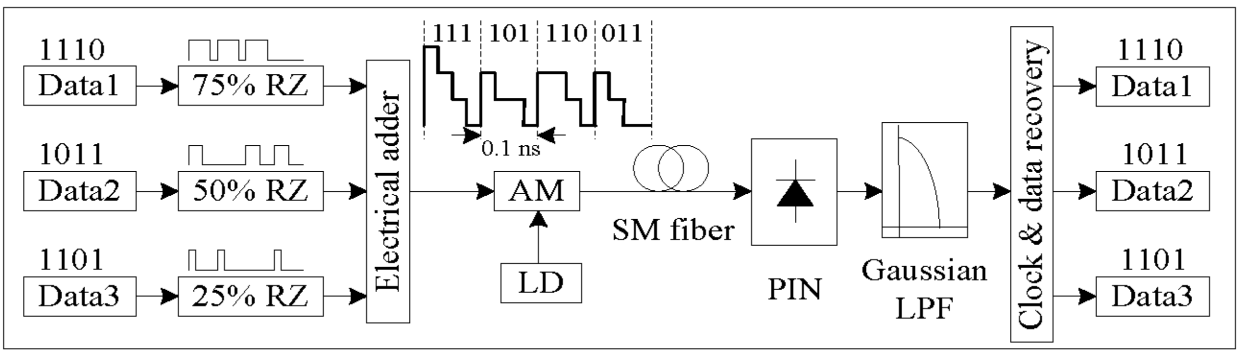

Fig. 1. Example of DCDM system for multiplexing 3 users.

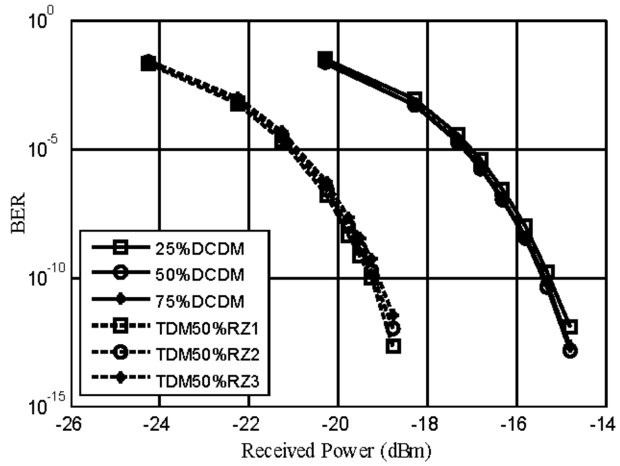

Fig. 2. Receiver sensitivity of DCDM and TDM.

Fig. 3 shows the effect of chromatic dispersion on the performance of the two multiplexing techniques which are tested at the same transmitted power. In DCDM technique, all users show almost similar behavior at positive and negative chromatic dispersions. Users with 25% and 50% duty cycles have chromatic dispersion of ±100 ps/nm/km at BER of 1e-9 and it is ±140 ps/nm for the user with 75% duty cycle. For the TDM technique, the users can sustain the dispersion of around ±84 ps/nm/km at the same BER. This result shows that, the DCDM technique is more robust to dispersion in comparison with TDM technique.

In Fig. 4 the BER versus bit rate is tested on a fixed fiber length and transmission power for both the DCDM and TDM techniques. In DCDM technique, user with 75% duty cycle can support around 2 Gbps more bit rate than the other two users at BER of 1e-9. In TDM technique, BER of all users varies approximately similarly at different bit rates. The worst user in DCDM technique still can support around 0.5 Gbps more bit rate than TDM users. Results in Fig.4 confirm the results in the previous figure, in which, the DCDM technique can support longer distance and/or higher bit rate than TDM technique at non-zero dispersion system.

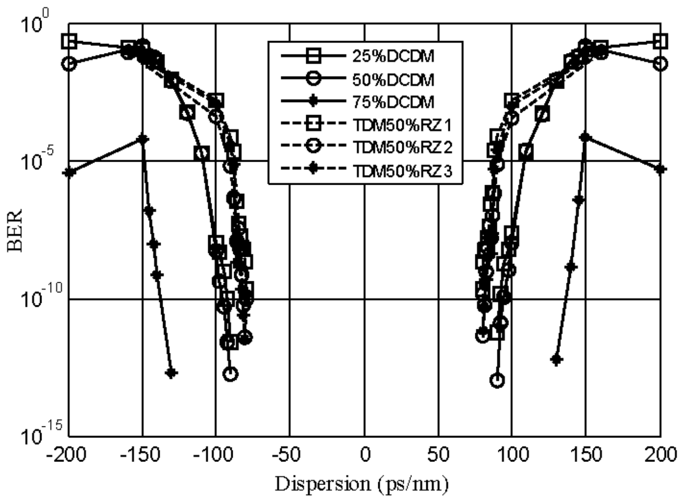

Fig. 3. Chromatic dispersion for DCDM and TDM technique for 3 channels.

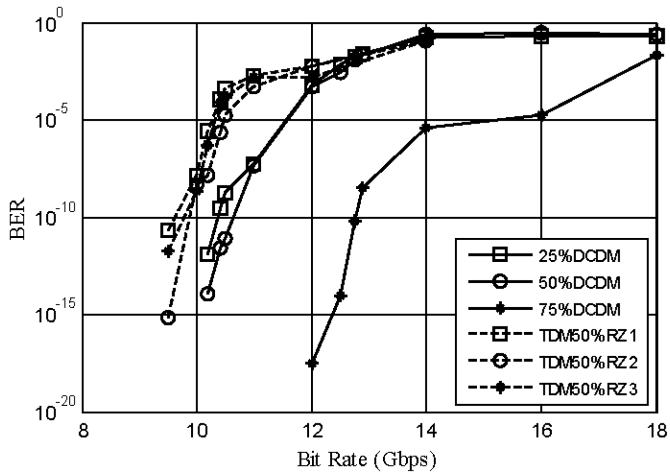

Fig. 4. BER versus data rate for DCDM and TDM technique.

VI. CONCLUSION

In this paper, Duty-cycle Division Multiplexing (DCDM) implementation on RZ modulation is discussed. Basic parameters which are important to determine the system performance were investigated. In the back-to-back receiver sensitivity, it is 3.7 dB worse in comparison with TDM. We also showed that the 30 Gbps DCDM has better tolerance to the chromatic dispersion in comparison to 30 Gbps TDM system. In other result, we presented that, in a fixed transmission power and fiber length, DCDM system can support more bit rate compared with TDM system. All findings support the argument 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. 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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