Demonstration of 8-channels Simultaneous Multiplexing Using 8-chip Electrical Codes for 10 Gbit/s ECDM-PON

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Abstract: First time 8-channels electrically code division multiplexing technique for optical access networks is demonstrated at a chip-rate of 10 Gchip/s. The technique enables error-free transmission of 1.25 Gbit/s × 8-channels over 20 km single-mode-fiber.

OCIS codes: (060.2330) Fiber optics communications; (060.4230) Multiplexing

1. Introduction

For next generation access (NGA) networks, the standardizations of passive optical network (PON) systems based on time-division-multiplexing such as 10 G E-PON and XG-PON are being discussed in IEEE 802.3av and ITU-T/F-SAN in order to provide higher bandwidth. Also at academic societies, 10 Gbit/s PON systems are extensively presented and discussed [1].

As one alternative NGA technology, we have proposed a PON scheme using code division multiplexing (CDM) technologies, which is called electrically-CDM-PON (ECDM-PON) and the architecture is shown in Fig. 1 [2, 3]. CDM technologies have been widely deployed in wireless communication and also studied in fiber optic communications due to its attractive features. We have also experimentally demonstrated CDM-PON co-existing with G-PON in a single mode fiber and using the same optical distribution network (ODN) [4]. The ECDM-PON consists of optical network units (ONUs) and an optical line terminal (OLT), they are connected through the optical fiber and optical splitters. CDM signals encoded in the electrical domain are optically transmitted on the PON. And, ONUs and OLT receive the desired signal by using electronic decoder composed of a correlator and a decision circuit [3].

Previous works from our group have been reported a 2 Gchip/s ECDM-PON using a CCD matched filter [3-5]. Considering the trend of current optical access networks, however, the total capacity of over 10 Gbit/s will be required in the NGA networks. Recently, 1.25 Gbit/s × 2-channels ECDM using an 18 Gchips transversal filter was reported [6].

In this paper, first time we present 1.25 Gbit/s × 8-channels ECDM technique at a chip-rate of 10 Gchip/s. Simultaneously, an error free transmission of ECDM over 20 km of single mode fiber is demonstrated with a simple configuration.

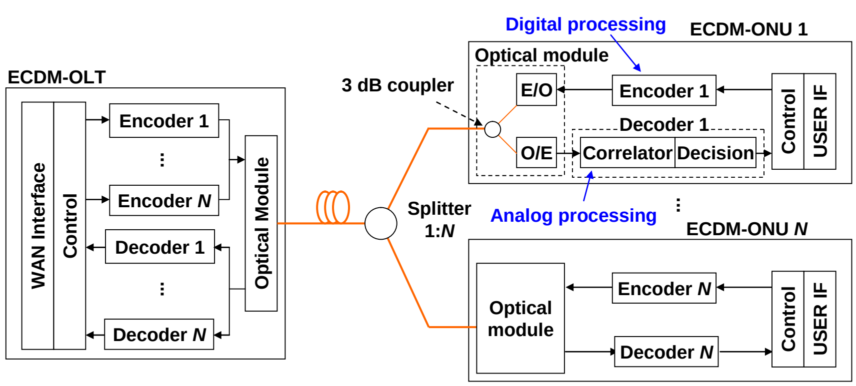

Fig. 1. ECDM-PON architecture.

2. Experimental setup

Figure 2 shows an experimental setup for 8-channels ECDM using a 10 Gchip/s correlator. In 8-channels ECDM, a 9-level signal generation is required since 8 encoded signals are combined with chip synchronization. Tx generates the 9-level optical signal which contained 8-multiplexed and encoded data at 10 Gchip/s (1.25 Gbit/s × 8-channels). By 4-channels (4-ch.) pulse pattern generator (PPG) and a power combiner, 9-level electric signal was generated. Each port of the 4-ch. PPG can output 2-level signal.

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The 2-level signal pattern output from port 1 of the PPG is expressed in the following equation;

$$p_1(t) = \{d_1(t) \cdot c_1(t)\} \bmod 2 \qquad (1)$$

where $d_1(t)$ and $c_1(t)$ are the data pattern of Channel 1 and the spreading code pattern (1 or 0), respectively. The data for the remaining 7-channels were output from ports 2-4 of the PPG. The 2-level signal pattern output from PPG m (m is PPG number 2-4.) is expressed in the following equation;

$$p_m(t) = \left\lfloor \frac{1}{2^{m-2}} \sum_{k=2}^{8} d_k(t) \cdot c_k(t) \right\rfloor \bmod 2 \qquad (2)$$

where $d_k(t)$ and $c_k(t)$ are the data pattern of Channel k and the spreading code pattern (1 or 0), respectively. In this experiment, the data pattern of each channel was 1.25 Gbit/s PRBS 2^9-1, and was encoded by 8 chips orthogonal Walsh code sequence. The signal voltage of each port was given added weight as shown in Fig. 2. The output signals from the PPG were fed to the power combiner with chip synchronization and the 9-level signal contained 8-channels encoded data was output. The chip synchronization of the output signals were carried out by delay controllers on PPG.

The electric 9-level signal was modulated by using a distributed feedback laser diode (DFB-LD) and an electro-absorption modulator (EAM) at the wavelength of 1550 nm. Figure 3 illustrates the 9-level signal modulation using an EAM. As shown in Fig. 3(a), the EAM has a linear RF input range of approximately 1.4 V. Thus, the bias and the amplitude of the electric 9-level signal were adjusted in the linear input range and the signal was optically modulated by the EAM as shown in Fig. 3(c). After the optical signal was amplified by an Erbium-doped fiber amplifier (EDFA), the signal was launched into the 20 km single mode fiber (SMF). The optical power launched into SMF was +9 dBm.

The Rx is consisted of a PIN-PD, a RF amplifier, a 10 Gchip/s correlator for decoding, a limiting amplifier, and an error detector (ERD) for BER measurements. The correlator operates as a finite impulse response filter. A block diagram of our 10 Gchip/s correlator is shown in Fig. 4. The 10 Gchip/s correlator is composed of passive RF components. The analog delay lines are implemented by variable RF delay lines. And each tap coefficient is determined by existence or nonexistence of broadband pulse inverter which inverts the polarity of the signal. When the pulse inverter exists, the tap coefficient is +1. On the other hand, when it does not exist, the tap coefficient is -1. Therefore, the correlator can generate an 8-chip bipolar code with 100-ps interval between each chip.

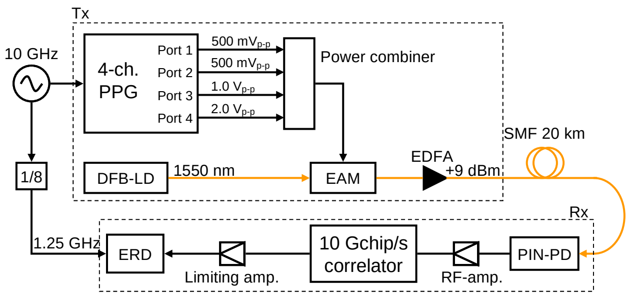


Fig. 2. Experimental setup.

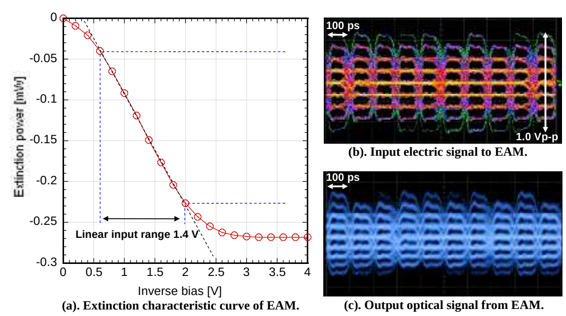


Fig. 3. Multi-level signal modulation using an EAM.

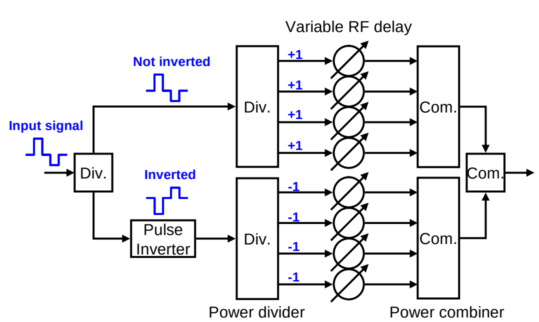
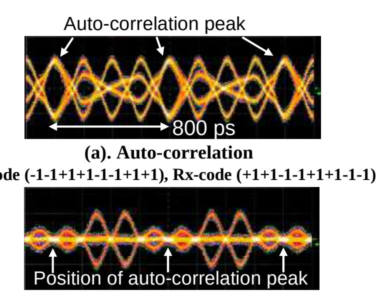


Fig. 4. Block diagram of a 10 Gchip/s correlator.



(b). Cross-correlation

Tx-code (-1+1+1-1+1-1-1+1), Rx-code (+1+1-1-1+1+1-1-1)

Fig. 5. Auto-correlation and cross-correlation

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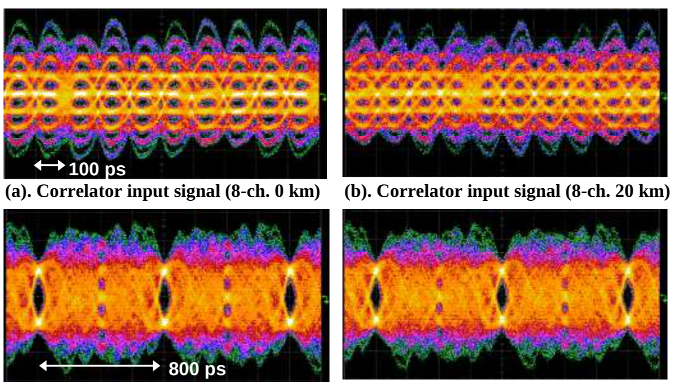
3. Result and discussion

Figure 5(a) and (b) show the auto-correlation and the cross correlation output from a 10 Gchip/s correlator when the number of channels was 1. In Fig. 5(a), auto-correlation peaks with clear eye openings at 800-ps intervals can be observed since the code-pattern matched with its reverse code and intended signal was decoded. On the other hand, in Fig. 5(b), the amplitude of cross-correlation is zero at the positions of auto-correlation peaks since the code-pattern did not match and the signal was not decoded.

Figure 6(a) and (b) show eye diagrams of the signals input to the correlator when the number of channels was 8. Comparing Fig. 6(a) with Fig. 3(c), the edge of the waveform becomes round by band limitations of the PIN-PD and the RF amplifier. In Fig. 6(b), the eye diagram after 20km transmission is distorted by the accumulation of the chromatic dispersion. Figure 6(c) and (d) show eye diagrams of the decoded signal. Clear eye openings after decoding were obtained and considerable waveform distortion was not observed even after 20 km optical transmission.

The BER performance is shown in Fig. 7. The received optical power in Fig. 7 is the measured power at the input of the PIN-PD. As shown in Fig. 7, error-free (<1 × 10^{-9}) was achieved in all cases. The power penalty between 1-channel and 8-channels is 1.5 dB and the power penalty with the 20 km transmission is 0.5 dB. The power budget of this system is 15 dB which can be enhanced to improve the SNR of multi-level signal and the Rx sensitivity. According to the code theory of orthogonal sequences, there are no multiple access interferences of not intended channels at the point of auto-correlation peaks. Therefore, ECDM system using 8-chip orthogonal sequences can accommodate 8-channels, the channel number equals to the number of codes. In addition, the SNR of the decoded signal is improved 9 dB by the decoding process using 8-chip spreading codes, theoretically [3]. Thus, the clear eye openings and error free optical transmission are obtained in this 8-channels ECDM experiment.



(a). Correlator input signal (8-ch. 0 km) **(b). Correlator input signal (8-ch. 20 km)**

(c). Correlator output signal(8-ch. 0 km) **(d). Correlator output signal (8-ch. 20 km)**

Fig. 6. Eye diagrams

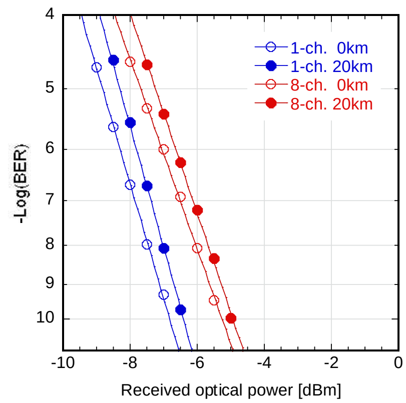


Fig. 7 .BER performance of 10 Gchip/s ECDM

4. Conclusion

First time we have demonstrated 1.25 Gbit/s × 8-channels ECDM technique at a chip-rate of 10 Gchip/s. As an experimental result, clear eye opening and error-free transmission over 20 km of single mode fiber were obtained with a simple configuration. Further improvements of ECDM-PON will be studied to enhance the power budget.

5. References

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