8x8 Full-duplex Demonstration of Asynchronous, 10Gbps, DPSK-OCDMA System using Apodized SSFBG and multi-port En/Decoder

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Abstract *We develop a novel apodized, 16-level-phase-shifted SSFBG encoder/decoder, which can improve the system performance of OCDMA system. Error free (BER<10^{-9}) transmissions of 8x8 full-duplex, asynchronous, 10Gbps, DPSK-OCDMA system over 50km are successfully demonstrated.*

Introduction

A symmetric Gigabit fiber-to-the-home (FTTH) service is required to meet the demands of future high bit rate applications[1]. Optical code division multiple access (OCDMA) is one promising candidate for gigabit-symmetric FTTH[1,2]. It has unique features of full asynchronous transmission, low latency access, soft capacity on demand as well as optical layer security. Recently, for the coherent time-spreading (TS-) OCDMA, the multi-port OCDMA encoder/decoder (E/D) has the unique capability of simultaneously processing multiple time-spread optical codes (OCs) with single device[3], which makes it a potential cost-effective device to be used in the optical line terminal (OLT) of an OCDMA network to reduce the number of encoder/decoders. Meanwhile, the phase-shifted superstructured fiber Bragg grating (SSFBG) E/D is another attractive TS-OCDMA E/D, which has the ability to process ultra-long TS-OC with polarization independent performance, low and code-length independent insertion loss, compactness as well as low cost for mass production[4]. Hybrid using different types of the E/D in an OCDMA network is expected to significantly improve the system flexibility and performance[5]. Very recently, we have successfully demonstrated a full-duplex demonstration of fully-asynchronous, 10 Gbps, differential phase shift keying (DPSK-) OCDMA system[6]. However, in this experiment, the number of users in uplink is up to four due to the non-ideal fabrication condition for SSFBG gratings.

In this paper, we newly develop a novel 16-chip, 16-phase-level-shifted SSFBG E/D using the apodization technique to improve the uplink performance in the OCDMA system with the hybrid E/Ds. With the developed SSFBG, error free transmissions of an asynchronous, full-duplex, 8-user, 10Gbps DPSK-OCDMA system over 50 km are successfully demonstrated for the first time.

16-chip, 16-level-phase-shifted SSFBG with Apodization Technique

The apodization technique refers to the refractive index change to approach zero at the end of each grating as shown in Fig. 1. In this experiment, we prepare eight apodized SSFBGs (Code01~08), the center wavelength is 1550.98 nm, chip length is ~0.52 mm, total length of grating is 8.32 mm, and each chip is apodized. Figures 1 show the encoding/decoding waveforms of uniform and apodized SSFBG, respectively. The duration of the generated OC is ~80 ps, chip-rate 200 Gchip/s. The peaks of each individual chips of encoding/decoding waveforms generated from the uniform SSFBG is not clear. On the other hand, the apodized SSFBG generates clear encoding/decoding waveforms compared with uniform one.

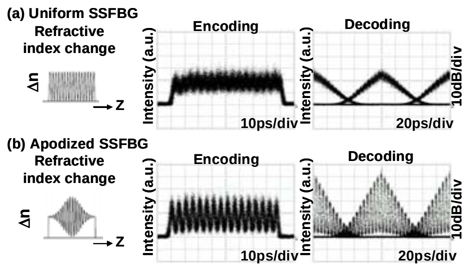

Fig. 1: Refractive index profile, encoding and decoding waveforms of uniform and apodized SSFBGs.

Experiment

Figure 2 shows the experimental setup of full-duplex OCDMA system. In this experiment, we simultaneously transmitted both down- and up-link. It means the full-duplex demonstration. OCDM Tx consists of a mode-locked laser diode (MLLD), a $LiNbO_3$ phase modulator (LN-PM), and erbium-doped fiber amplifiers (EDFAs). The MLLD generates 1.8 ps optical pulses at the repetition rate of 10.71 GHz with the central wavelength of 1551 nm. The generated signal was modulated with the DPSK format by the LN-PM. The frame contains 2^{31}-1 pseudo random bit sequence (PRBS) payload and forward error correction (FEC) parity. Please note that the use of FEC at 10Gbps in FTTH syatems will likely become a real-world scenario because of the low-cost.The FEC is Reed-Solomon code (RS(255, 239)). The data rate is 10.71 Gbps (10 G for payload + 7% FEC overhead). An OCDM Rx consists of a fiber-based interferometer and a dual-pin photo diode for the DPSK detection. In this experiment, we employ the clock-and-data

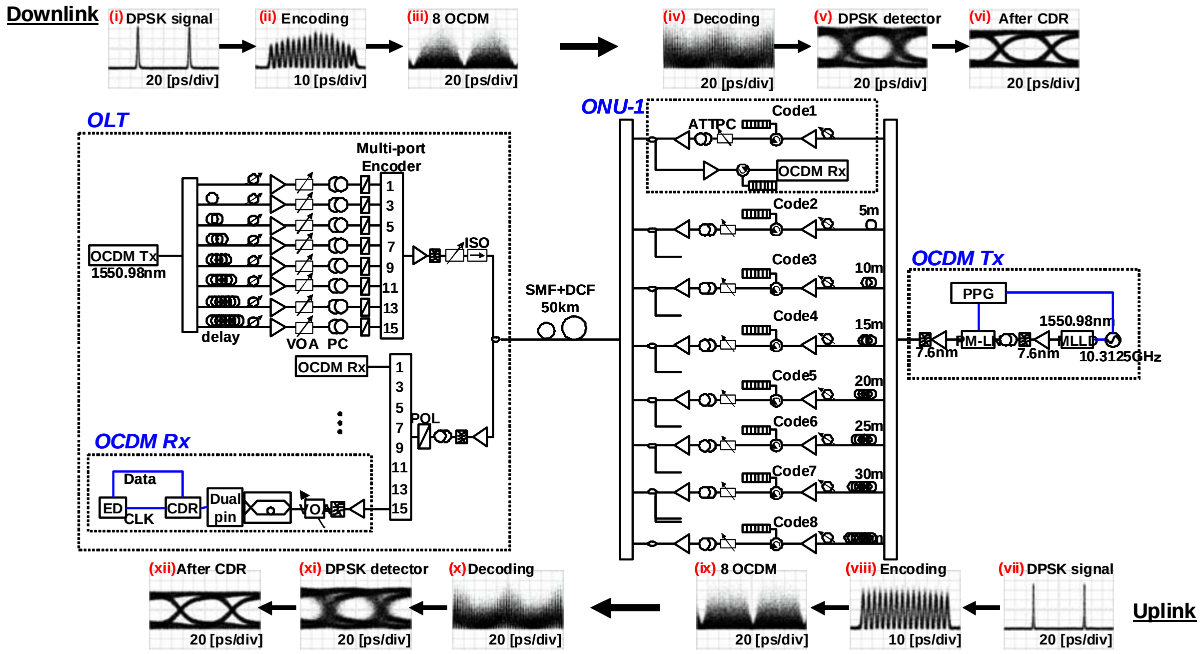

Fig. 2: Experimental setup and results.

recovery (CDR) circuit and the error detector (ED) after the DPSK detection for the bit error rate (BER) measurement.

In downlink, the output of OCDM Tx (Fig. 2 (i)) is split into 8 branches in a truly-asynchronous manner with equal power, random delay, random bit phase and launched into the multi-port encoder, which simultaneously generates eight 16-chip (200 Gchip/s) OCs as shown in Fig. 2 (ii). These 8-OCDMA signals are multiplexed (as shown in Fig. 2 (iii)) and then launched into 50 km transmission fiber, which is composed of a fiber pair of a single mode fiber (SMF) with a reversed dispersion fiber (RDF). After the fiber transmission, these OCDMA signals are split into 8 ONUs. Total loss budget from the OCDM Tx at the OLT to Rx at each ONU is about 30 dB, including 3 dB couplers, connectors, 50 km fiber, and the splitting loss. At each ONU, the received signal was decoded by the 16-chip, 16-phase-shifted SSFBG decoder as shown in Fig. 2 (iv). The decoded signal was detected by the OCDM Rx. Insets (v, vi) in Fig. 2 show the eye diagrams of signals after the DPSK detector and CDR, respectively.

In uplink, as well as downlink, the output of OCDM Tx (Fig. 2 (vii)) is split into 8 branches in a truly-asynchronous manner and launched into 8 different SSFBG encoders, which are the same codes as downlink, respectively. Inset (viii) in Fig.2 shows the waveform of the generated OC. The 8-OCDMA signals are asynchronously multiplexed as shown in Fig. 2 (ix), and then launched into 50 km fiber. At the OLT, the 8-OCDMA signals are simultaneously decoded by the multi-port decoder. The decoded signal is detected the same method as downlink. Insets (x, xi, and xii) in Fig. 2 show the eye diagrams of signals after the OCDM decoder, DPSK detector, and CDR, respectively.

Figures 3 show BER performances of up- and down-link after 50 km fiber transmission in case of unidirectional and full-duplex with/without FEC. In full-duplex with FEC, error free (BER<10^{-9}) transmission has been achieved for all the users in both down- and up-link after 50 km transmission. The power penalties of up- and down-link BERs between unidirectional and full-duplex are mainly caused by back reflected noises resulting from connectors, couplers, and other optical devices. We can improve the transmission performance using the different codes between up- and down-link.

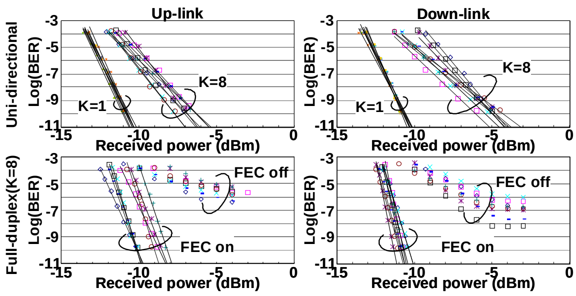

Fig. 3: BER measurements.

Conclusions

We have newly developed an apodized 16-phase-level-shifted SSFBG E/D. With the developed SSFBG, error free transmissions of asynchronous, full-duplex, 8-user, 10Gbps DPSK-OCDMA system over 50 km are successfully demonstrated.

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