500 ns, 100 ns, respectively. Minimum and maximum received optical powers at a BER of 10^-9 were -28.5 dBm and over -3 dBm, respectively. Because forward error correction (FEC) is assumed to be adopted for transceivers in 10G-EPON systems, a 33-dB loss budget and a 25.5-dB dynamic range can be achieved and exceed values standardized as P830 in IEEE 802.3 av; a 29-dB loss budget and a 22-dB dynamic range.

![Schematic diagram of burst transmitter with BLW-CMR technique and BLW of LD anode and BLW of LD cathode](image)

4. Summary

We have developed a 500-ps response burst-mode transmitter with the ac-coupled differential interface for 10-Gbit/s-class PON systems by using a novel BLW-CMR technique. The response time is the fastest reported for a burst-mode transmitter. Our BLW-CMR technique eliminates BLWs on anode and cathode terminals by producing same transient responses of capacitors and canceling them in the common-mode rejection. The feasibility of this technique was demonstrated experimentally by using a prototype operating at 10.3125 Gbit/s. The T_{out}/T_{in} time and the output power were 500 ps and +4.4 dBm, respectively. This fast response and the high output power contribute to improvements of the transmission efficiency and the loss budget in PON systems, respectively. Our developed transmitter and APD receiver could achieve a loss budget of 33 dB and a dynamic range of 25.5 dB at a BER of 10^-9 for 10G-EPON systems.

References

6) IEEE P802.11a Task Force, [http://www.ieee802.org/11a/](http://www.ieee802.org/11a/)

### Duplex, Fully-Asynchronous, 10Gbps x 8-user DPSK-OCDMA Field Trial Using a Multi-port En/Decoder and SSFBG En/Decoders

Nobuyuki Kataoka(1), Naoya Wada(1), Xu Wang(2), Gabriella Cinetti(3), Aldra Sakamoto(4), Yoshihiro Terada(4), Tetsuya Miyazaki(5), and Ken-ichi Kitayama(6)

1) National Institute of Information and Communications Technology, 4-2-1, Nukui-kitamachi, Koganei-shi, Tokyo 184-8795, Japan
2) School of Engineering and Physical Sciences, Heriot-Watt University, Riccarton, Edinburgh EH14 4AS, UK
3) Department of Applied Electronics, University of Roma Tre, Rome, Italy
4) Optics and Electronics laboratory, Fuglafjordur Ltd., 1440 Manzushiu, Oita, Oita 805-850, Japan
5) Department of Electrical, Electronic and Information Systems, Osaka University, 2-1 Yamadaoka, Suita, Osaka 565-0871, Japan

**Abstract:** We present field trial of duplex, fully-asynchronous, 10-Gbps, 8-user DPSK-OCDMA system. A combination of single multi-port en/decoder at central office and SSFBG en/decoder at each ONU can enable cost-effective configuration.

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OC3c40s (060.2330) Fiber optics communication, (060.950) Phase modulation, (060.420) Multiplexing

1. Introduction

Optical code division multiple access (OCDMA) is one promising candidate for next-generation broadband multiple access technique with unique features of full asynchronous transmission, low latency access, soft capacity on demand as well as optical layer security. By combining OCDMA with wavelength division multiplexing (WDM) technique, high capacity in access networks can be achieved, which in prospective can enable gigabit/symmetric fiber-to-the-home (FTTH) [1-2]. There are two different approaches for multi-user coherent OCDMA system: synchronous and asynchronous OCDMA. In synchronous OCDMA, proper timing coordination is required to carefully avoid interference between signal and interferences [3-4]. However, the asynchronous capability is essential in practical OCDMA systems [1-2, 5]. Recently, for coherent time-spreading (TS-) OCDMA, multi-port OCDMA encoder/decoder has the unique capability of simultaneously processing multiple time-spread optical codes (OCs) with single device [6], which makes it a potential cost-effective device to be used in the central office of OCDMA network to reduce the number of encoder/decoders [2]. Meanwhile, phase-shifted superstructured fiber Bragg grating (SSFBG) encoder/decoder is another attractive TS-OCDMA encoder/decoder, which has the ability to process ultra-long TS-OC with polarization independent performance, low code-length independent insertion loss, compactness as well as low cost for mass production [7]. Hybrid using different types of the encoder/decoder in an OCDMA network is expected to significantly improve the system flexibility and performance [8].

In this paper, we develop full-asynchronous 10Gbps interface OCDMA prototype for the first time and present a field trial of duplex, fully-asynchronous, 10 Gbps, 8-user differential phase shift keying (DPSK-) OCDMA system. A combination of single multi-port en/decoder at central office and SSFBG en/decoder at each ONU can enable cost-effective configuration. Moreover, 160 Gbit/s (10 Gbps x 8-OCMA x 2 WDM) downlink field trial is also demonstrated.

2. Duplex, fully asynchronous OCDMA prototype

Our developed OCDMA prototypes include 10Gbps interface OCDMA transmitters (Tx) and receiver (Rx). Figures 1 show configurations and photographs of the OCDM Tx and Rx, respectively. OCDM Tx consists of mode-locked laser diode (MLLD), LiNbO3 phase modulator (LN-PM), and OCDM Tx board, which convert the inputted 10Gbps signal into 10.3125 Gbps serial data with DPSK precoding and clock recovery. The MLDL generates ~1.8 ps optical

![OCDM Tx](image)

![OCDM Rx](image)

**Fig. 1.** Configurations and photographs of OCDMA prototype: (a) OCDM Tx and (b) OCDM Rx.
pulses at repetition rate of 10.3125 GHz. The signal was modulated with DPSK format by LN-PM. OCDM Tx is 19-inch x 3U sized rack and independently driven by the inputted 10Gbps signal without the external synthesizer. It allows full-asynchronous operation. On the other hand, OCDM Rx mainly consists of a fiber based interferometer, dual-pin photo detector (PD), and OCDM Rx board, which converts the DPSK detected signal into 10Gbps signal. At the ONU side, OCDM Rx includes the SSFBG decoder and is in 19-inch x 1U sized rack. The package of the SSFBG is 45 mm x 3 mm in size without temperature control.

3. Experimental setup and results

Figures 2 (a) and (b) show the experimental setups for downlink and uplink, respectively. We employed 4 OCDM Tx. Each OCDM Tx was independently driven by a pulse pattern generator (PPG) for the bit error rate (BER) measurement, a network analyzer, and two high-definition video (HDV) streaming systems, respectively. The central wavelengths of all Tx are 1551 nm. The data rate was 10.3125 Gbps (PRBS 2^7-1) and the signal format was DPSK is shown in insets (i) and (ii) in Fig. 2.

3.1 Downlink

In downlink case, each Tx output was split into 2 branches and launched into the 16x16 port encoder that can generate 16 coherent TS-OCs with 16-chip and 200 Gb/s for this application was fabricated by NEL. We used all the odd input ports of the encoder to generate 8 different OCs. Inset (ii) in Fig.2 shows the waveform of the generated OC. The 8 OCDMA signals were asynchronously multiplexed, and then launched into 100 km field single mode fiber (SMF), which is part of JGII installed in Tokyo metro area [9]. Inset (iii) in Fig.2 shows the waveform of this signal. The transmitted signals were split into 8 ONUs. The received signal was decoded by the 16-chip, 16 phase-shift SSFBG decoder fabricated by Fujikura at each ONU. The decoded signal was detected by a fiber based interferometer and balanced detector, which perform the DPSK detection. The clock-data-recovery (CDR) circuit regenerates the data and clock signals and forwarded to the BER tester (BERT). Insets (iv), (v), and (vi) in Fig. 2 show the eye diagrams of the signals after the OCDM decoder, DPSK detector, and CDR, respectively.

3.2 Uplink

In uplink case, as well as downlink case, each Tx generated 10.3125 Gbps DPSK signal is shown in inset (vii) in Fig. 2. These outputs were split into 2 branches and launched into 8 different SSFBG encoders, which were the same device as SSFBG decoder used in downlink experiment, respectively. Inset (viii) in Fig.2 shows the waveform of the generated OC. The 8 OCDMA signals were asynchronously multiplexed, and then launched into 100 km field SMF. Inset (ix) in Fig.2 shows the waveform of this signal. The 8 OCDMA signals were decoded by the 16x16 port decoder simultaneously. The decoded signal was detected the same method as downlink case. Insets (x), (xi), and (xii) in Fig. 2 show the eye diagrams of the signals after the OCDM decoder, DPSK detector, and CDR, respectively. Figure 3 (c) shows the BER performances of uplink after field transmission. In this case, 4 fully-asynchronous OCDMA has achieved error free for all the users. However, in 8 OCDMA case, most of the users have not achieved error free except 2 users. This is due to the non-ideal fabrication condition for SSFBG gratings. Adding the forward error correction (FEC) parity, which is Reed-Solomon code (RS(255, 239)), to the data stream, we measured BER performance at 10.71 Gbps (10 G for payload + 7% FEC overhead) Figure 3 (b) shows the BER performances of uplink after field transmission. Error free has been achieved for all the users after field transmission.

4. Conclusions

We have developed full-asynchronous 10Gbps interface OCDMA prototype for the first time. We have also conducted a field trial of duplex, full-asynchronous, 10Gbps, 8-user DPSK-OCDMA system. A key enabler for cost-effective configuration is a single multi-port en/decoder at central office and SSFBG en/decoder at each ONU. A promising deployment scenario would be to overlay this duplex OCDMA system onto existing WDM PON system for the system scale-up on demand.

References