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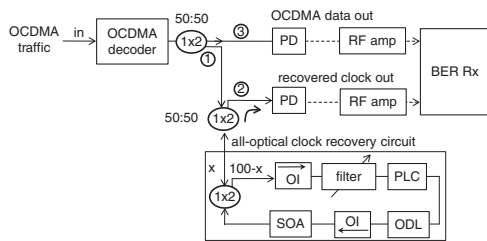
# OCDMA receiver with built-in all-optical clock recovery

S.K. Idris, T.B. Osadola and I. Glesk

A receiver that incorporates an all-optical clock recovery approach for synchronisation suitable for use in incoherent OCDMA transmission is demonstrated. The developed solution was implemented and tested in a multiuser environment using the 2D-WHTS coding scheme on incoherent OCDMA transmission with 2.5 Gbit/s data rate. The receiver with built-in all-optical clock recovery was tested by taking the BER for the received data when synchronised with the all-optically recovered clock from the incoming OCDMA traffic and when an RF synthesiser was used to generate the clock. Improvement of ~7.5 dBm was observed with the all-optical clock recovery approach. The related eye diagrams and the wavelength spectrum were also recorded.

**Introduction:** Optical code division multiple access (OCDMA) can offer some advantages including flexibility in data rates, enhanced scalability and quality of service depending on the network demands, including the support for a bursty traffic. To improve OCDMA system performance further with autocorrelation time gating [1] the receiver synchronisation is critical. Implementations of a wide variety of signal extraction techniques [2] for synchronisation were developed mostly in WDM [3] and OTDM [4], however their application in OCDMA is limited. Clock and data recovery for OCDMA was reported for example in [5, 6]; however these approaches were not implemented all-optically. The all-optical clock recovery (AOCR) system was very important for providing a very low jitter signal as was demonstrated all-optically using drop gates such as a nonlinear optical loop mirror (NOLM) and a terahertz optical asymmetric multiplexer (TOAD) [7]. Realisation of a suitable all-optical clock extraction circuit which can recover a timing signal from an incoming OCDMA data stream and produce an optical clock without an intermediate electronic stage is needed. In principle, recovering an optical clock from incoming data at given bit rates means extracting a new periodic signal with a period reciprocal of the bit rate, while free of information carried by data and without phase noise [2]. Laboratory testing usually relies on a global clock and fast photodetector to detect the autocorrelation peaks and to avoid the degradation due to the multi-access interference (MAI). However, a global clock is not always available, thus a more practical approach is needed. In this Letter, we present for the first time to our knowledge an OCDMA receiver which incorporates a simple all-optical clock recovery circuit based on a fibre ring laser [3] and fibre Bragg grating (FBG) correlator to detect optical codes composed of two-dimensional wavelength hopping time spreading (2D-WHTS) codes with picosecond (ps) multi-wavelength pulses.

**Receiver with AOCR:** Fig. 1 shows the developed receiver whose input is an OCDMA signal and the output is decoded OCDMA data and an all-optical clock signal recovered from the received signal.

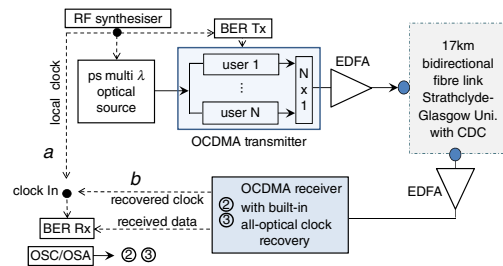


**Fig. 1** Schematic diagram of OCDMA receiver with built-in all-optical clock recovery

ODL: optical delay line; PLC: polarisation controller; OI: optical isolator; PD: photodiode; BERT: bit error rate tester

The incoming OCDMA data is sent into the receiver where it is first decoded to produce the autocorrelation signal. Such decoded data is then split into two; one arm is sent to an 11 GHz optical photodiode (Nortel PP10G), while the other arm is sent to the AOCR circuit to produce the clock signal at the same rate as data. The operation of the all AOCR circuit relies on fast gain saturation of the semiconductor optical amplifier (SOA) by the incoming OCDMA data stream, resulting in cavity modulation leading to fibre laser locking. The cavity of the AOCR

circuit (see Fig. 1) was constructed from fibre pigtailed devices. The incoming data pattern and recovered clock signal were introduced into and extracted out of the loop, respectively by the (100-x); x optical fibre coupler. Two different coupling configurations (x=10 and x=20) were tested to investigate the optimal coupling ratio. Better results were obtained using x=10. A tunable optical filter was used for wavelength selection of the recovered optical clock, and a variable optical delay line (ODL) to adjust the laser cavity length of the AOCR to match the incoming OCDMA data rate (OC-48). When the ODL is adjusted so that the repetition rate of the input signal is equal to an integer multiple of the fundamental frequency of the fibre ring cavity (the AOCR circuit is properly synchronised with the input data signal) the cavity will be harmonically locked and the optical clock signal is being generated. The generated clock and decoded OCDMA data are then sent to the bit error rate tester receiver (BER Rx), as indicated in Fig. 2.



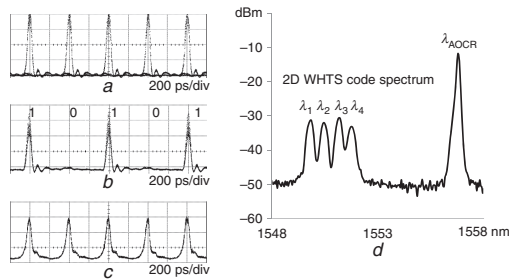
**Fig. 2** Field based multi-user OCDMA testbed

a BER Rx synchronised locally from RF synthesiser  
 b BER Rx synchronised by all-optically recovered clock generated by OCDMA receiver with built-in all-optical clock recovery  
 BER Tx: bit error rate transmitter; BER Rx: bit error rate receiver; MOD: data modulator; PD: photodiode; OSC: oscilloscope; OSA: spectrum analyser; CDC: chromatic dispersion compensation

**Experimental setup:** Fig. 2 shows the field based optical testbed. It consists of a multi-user OCDMA transmitter, a 17 km-long bidirectional fibre optic link and the receiver with the built-in AOCR under test.

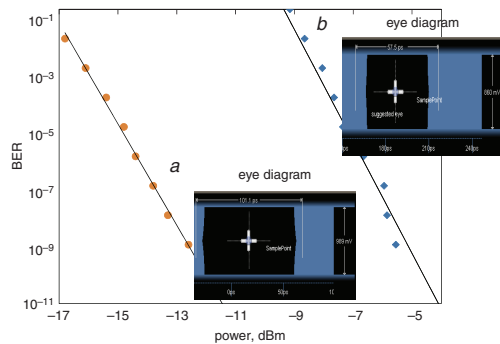
The experiment was implemented using 2D-WHTS OCDMA codes and four simultaneous users. A picosecond multi-wavelength source was used to generate four wavelength carriers  $\lambda_1=1551.72$  nm,  $\lambda_2=1550.92$  nm,  $\lambda_3=1552.52$  nm,  $\lambda_4=1550.12$  nm which were placed by OCDMA encoders based on FBG within 53 time chips, each having duration of ~8 ps, thus creating the 2D-(4,53) WHTS family of codes. The system running at OC-48 used a  $2^7-1$  PRBS data pattern generated by an Agilent N4903A BER tester. The OCDMA signal was then launched into the 17 km bidirectional fibre-optic link. The incoming signal was detected by the OCDMA receiver with AOCR. The receiver evaluation was performed by taking BER measurements for data received under two different ways of BER Rx synchronisation (see Fig. 2): a – using the clock (2.5 GHz sinusoidal wave) generated by the RF synthesiser (Agilent E4432B); b – using the all-optically recovered clock generated by the receiver under test from the received OCDMA data. An optical spectrum analyser and an oscilloscope were used for monitoring, as is indicated in Fig. 1.

**Results and discussion:** Fig. 3a illustrates the eye diagram of the received OCDMA data. Fig. 3b is an example of a data sequence '1010'. The example of the all-optically recovered clock from the received OCDMA data is in Fig. 3c (as seen by a bandwidth limited oscilloscope with 20 GHz optical sampling head). Fig. 3d shows the optical spectrum of the 2D-WHTS OCDMA codes and a wavelength  $\lambda_{AOCR}=1558$  nm of the all-optically recovered clock. Fig. 4 shows two separate BER curves with related eye diagrams for the received  $2^7-1$  PRBS OCDMA data. The first set (Fig. 4a) was obtained when the all-optically recovered clock was used to synchronise the BER Rx (see Fig. 2b), the other set (Fig. 4b) when the BER Rx was synchronised locally by the signal from the RF synthesiser (see Fig. 2a). Using the all-optically recovered clock for the BER Rx synchronisation resulted in a wider eye opening: 101.1 ps width and 989 mV height compared to 57.5 ps width and 860 mV height when using the local clock from the RF synthesiser.



**Fig. 3** Experimental results

*a* Eye diagram of decoded incoming  $2^7-1$  PRBS OCDMA data  
*b* Decoded data pattern '1010' for illustration only  
*c* All-optically recovered clock from received OCDMA data  
*d* Recorded optical spectrum of 2D-WHTS OCDMA code;  $\lambda_{AOCR}$  belongs to all-optically recovered clock signal



**Fig. 4** Measured BER and eye diagram for received  $2^7-1$  PRBS data

*a* Synchronisation done using all-optically recovered clock from received OCDMA data  
*b* Synchronisation done directly by clock from RF synthesiser

As demonstrated in Fig. 4, a very significant  $\sim 7.5$  dBm power budget improvement was noted when the all-optically recovered clock was used for the BER Rx synchronisation. This improvement results from the fact that the all-optically recovered clock when used to synchronise the receiver 'follows' the (time) jitter OCDMA signal and will 'drag' it to follow the jitter which in turn 'eliminates' the jitter and thus improves BER.

**Conclusion:** For the first time, an optical receiver with a simple and robust all-optical clock recovery built-in for use in OCDMA has been proposed and successfully demonstrated. The receiver was evaluated under realistic out of laboratory conditions at OC-48 data rate to

process 2D-WHTS OCDMA codes based on multi-wavelength picosecond pulses. A significant power budget improvement of  $\sim 7.5$  dBm was achieved with a bigger and wider eye opening when compared with BER results obtained using the all-optically recovered clock from received data against using a clock generated locally by the RF synthesiser.

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One or more of the Figures in this Letter are available in colour online.

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