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Clock recovery based on in-band pilot for 160 Gbps OTDM signal

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Abstract

We present a novel opto-electronic clock recovery concept based on in-band phase-modulated pilot insertion. Successful retrieval of a 40-GHz clock and error-free demultiplexing of 160-to-40 Gbit/s is demonstrated.

1 Introduction

Clock recovery is an essential function of the receiver to synchronize to the transmitted data in an optical communication system. In optical time-division multiplexing (OTDM) network, the clock must be recovered at the base-rate in order to perform other functionalities such as data regeneration or demultiplexing. Typical clock recovery implementations consist in the interaction between the harmonics of the data signal and the locally generated clock in a phase comparator whose output is used in a phase-locked loop (PLL) for synchronization. Different non-linearities such as four-wave mixing [1] or cross-phase modulation [2] in semiconductor optical amplifier, three wave-mixing in a periodically-poled lithium niobate (PPLN) waveguide [3] or electro-absorption modulation [4], have been exploited to provide the phase comparator functionality. The major difficulty present in these approaches is that a PLL is required to accomplish the synchronization whose phase comparator must hold a very high time-resolution of the order of the bit-slot duration.

In this paper we demonstrate a novel clock-recovery method based on extracting an inserted phase-modulated pilot in the data spectrum. This approach eliminates the

Figure 1 Experimental setup for self-clocking based on the in-band pilot method. MUX: Optical Time-domain Multiplexer, FBG: Fiber-Bragg Grating, OBF: Optical Bandpass Filter, PD: Photodetector, DEMUX: Demultiplexer, BERT: Bit-error rate tester.

need of an ultrafast phase comparator and a phase-locked loop (PLL) which simplifies the system. Since we do not require a PLL, no preamble bits are required, making the concept also suitable for clock recovery of bursty data. In the experiment, demultiplexing from 160 Gbits to 4×40 Gbit/s is performed with error-free performance using the proposed concept.

2 Experiment

The experimental setup to demonstrate the in-band pilot insertion and clock extraction is shown in Fig. 1. The data signal is generated by a fiber-based mode-locked laser (FMLL) at 39.812 GHz tuned to 1555.7 nm. The pulses are RZ on-off keying (OOK) modulated with a pseudo-random bit sequence (PRBS) of 2^7-1 at one single polarization and subsequently multiplexed up to 160 Gbit/s through a polarization-maintaining fiber-delay multiplexer. The data signal is with an average power of

Figure 2 Spectra and waveforms of the 160 Gbit/s data signal after pilot insertion. Top-left inset: optical spectrum of the in-band pilot clock.

Figure 3 Optical spectrum and eye diagram of the data signal after pilot extraction. Top-left inset: optical spectrum of the recovered clock.

Fig. 4 Single side-band phase noise of the master clock and the recovered clock.

Figure 5 BER performance of the 40 Gbit/s tributaries using the master clock and the recovered clock

6dBm. The pilot is generated by a CW laser tuned to 1552.5 nm which is phase modulated at 10 GHz by the master clock. The driving power is optimized to intensify the first order sidebands produced by the phase modulation[5]. Subsequently, phase modulated signal is coupled with the data signal to get the pilot inserted in the data signal band. In the receiver part, the in-band pilot is extracted at port 3 of the circulator by means of a Fiber-Bragg Grating (FBG) centered at 1552.5 nm. Later on, a tunable optical band-pass filter is used to select the optical carrier and the first-order upper sideband, and thus the clock is recovered by optical mixing detection associated to a photodetector (PD) and then amplified and filtered by an electrical high-Q band-pass filter. Finally, the data signal after pilot extraction and the recovered clock are used as an input and driver of the EAM demultiplexer, respectively, in order to perform bit-error-rate (BER) tests on the tributaries.

3 Discussions and results

Fig. 2 illustrates the spectrum of the pilot inserted in the data signal band. The inset on the top-left side shows a zoom-in of the pilot where it can be appreciated several sidebands generated by phase modulation. The inset on the top-right side shows the 160 Gbit/s traces after pilot insertion.

The extraction of the pilot creates a curve in the data signal spectrum as depicted in Fig. 3. The extracted pilot is filtered by an OBPB with 0.25 nm bandwidth to select

the pilot carrier and its first-order upper sideband, which is shown in the inset.

To investigate the performance of the proposed clock recovery technique, we carried out single sideband (SSB) phase noise measurements on the recovered clock using an electrical spectrum analyzer (Fig. 4). Integrating the SSB phase-noise over the frequency range from 100 Hz to 10 MHz, yields a timing jitter of 164 fs. In the demultiplexing stage, the clock frequency is quadrupled to 40 GHz and in turn used to drive the EAM demultiplexer in order to extract 40 Gbit/s tributaries. In Fig. 5, the filled squares illustrate the bit-error-rate (BER) performance corresponding to the back-to-back configuration employing the master clock. Error-free operation is achieved with a received power of -6.5 dBm. The open squares represent the BER performance of the data after pilot insertion and extraction employing the master clock. Whereas the configuration employing the recovered clock shows an error-free performance with a received power of -5.3 dBm. This turns out in a power penalty of 1.2 dB, which includes pilot insertion, extraction and clock recovery.

4 Conclusion

We have demonstrated a novel clock recovery method for ultra-high speed OTDM signals. The clock insertion and extraction was successfully achieved with a power penalty of about 1.2 dB. No ultrafast phase comparator is required for the clock recovery. The method seems promising for clock recovery at higher bit rates (e.g. 320 and 640 Gbit/s) or bursty data.

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5 References

- 1 O. Kamatani and S. Kawanishi, Ultrahigh-speed clock recovery with phase lock loop based on four-wave mixing in a traveling-wave laser diode amplifier, *J. Lightwave Technol.* 14, 1757-1767(1996).
- 2 H. C. Hansen Mulvad, E. Tangdiongga, H. de Waardt, and H. J. S. Dorren, 40 GHz clock recovery from 640-Gbit/s OTDM signal using SOA-based phase comparator, *Electron. Lett.*, 44, 146-148(2008).
- 3 L.K. Oxenlowe, et al., 640 Gbit/s clock recovery using periodically poled lithium niobate, *Electron. Lett.*, 2008. 44, pp. 370-371.
- 4 C. Boerner, V. Marembert, S. Ferber, C. Schubert, C. Schmidt-Langhorst, R. Ludwig, and H.G. Weber, "320 Gbit/s clock recovery with electro-optical PLL using a bidirectionally operated electroabsorption modulator as phase comparator," in *Optical Fiber Communication Conference*, Vol. 2 of 2005 OSA Technical Digest Series (Optical Society of America, 1996), paper 349-351.
- 5 G. Qi, et al., Optical generation and distribution of continuously tunable millimeter-wave signals using an optical phase modulator, *J. Lightwave Technol.*, 2005, 23, pp. 2687-2695.