EMULATING ETDM RECEIVERS BY OTDM RECEIVERS FOR HIGH SPEED SYSTEM MEASUREMENTS

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Abstract

Theory and experiment quantify to what extent OTDM receivers can emulate the performance of ETDM receivers. OTDM receivers can yield ~1dB better absolute sensitivities than ETDM receivers, but perform similar for sub-optimum optical filter bandwidths.

Introduction

Driven by the desire to steadily reduce the cost per transmitted information bit, per-channel data rates have continuously been increasing, leading to 40Gb/s systems commercially available today, and to even higher data rate systems being explored in research laboratories world-wide. Technologically, the push for higher data rates has always left behind the development of high-speed electronics. This has necessitated the use of *optical* time division multiplexed (OTDM) transmitters and receivers [1] until their economically more attractive *electrical* time division multiplexed (ETDM) equivalents became available [2]. Even today, OTDM receivers still represent a convenient way of performing 40Gb/s system tests [3]. With the co-use of two different receiver technologies, the important question of inter-comparability arises, i.e. the question of how closely OTDM receivers actually resemble ETDM receivers, both in terms of absolute sensitivity and in terms of robustness to performance degrading effects. This question becomes particularly striking when considering the completely different electrical receiver bandwidths within the two types of receiver.

This paper points out similarities and differences between the two receiver concepts, both by means of theory and experiment. To have good control over experimental parameters, we performed the measurements at 10Gb/s (ETDM) and 4x2.5Gb/s (OTDM).

Experiment

Figure 1 shows the experimental setup of our 10Gb/s ETDM receiver and 4x2.5Gb/s OTDM receiver. The common input signal was a 10Gb/s, 45% duty cycle return-to-zero (RZ) signal, generated by a 10GHz sinusoidally single-arm driven Mach-Zehnder modulator. The data was a pseudo-random bit sequence of length $2^{20}-1$. The extinction ratio of the data modulator was 14dB. A high-gain, low-noise EDFA was used as an optical preamplifier, and amplified spontaneous emission (ASE) was filtered by fiber Bragg gratings of various bandwidths B_o. The upper eye diagrams in Fig.1 correspond to the signals present in the ETDM receiver, for which the electroabsorption modulator (EAM) was not modulated, letting the optically filtered data pulses directly reach the photodiode. The lower eye diagrams represent the waveforms found in the OTDM receiver, which was realized by driving the EAM with a rectangular electrical signal of 25% duty cycle. This way, four tributaries at a reduced rate of 2.5Gb/s were generated. The extinction ratio for the EAM was 18dB. Opto-electronic conversion was performed, for both receivers alike, by a wideband (40GHz) photo-diode. Detection was followed by different 5th-order Bessel filters to emulate limited receiver bandwidths B_e. For the ETDM receiver, we set B_e=7.5GHz, for the OTDM receiver we chose B_e=1.5GHz. Due to the narrowband lowpass filtering for the OTDM receiver, the pulses were spread in time over four 10Gb/s-bit slots, while the maximum pulse height (s_1) was reduced by a factor of about four compared to its value for the ETDM receiver (cf. Fig.1). After filtering, the electrical signal was sampled at a rate of 10Gb/s (ETDM) and 2.5Gb/s (OTDM).

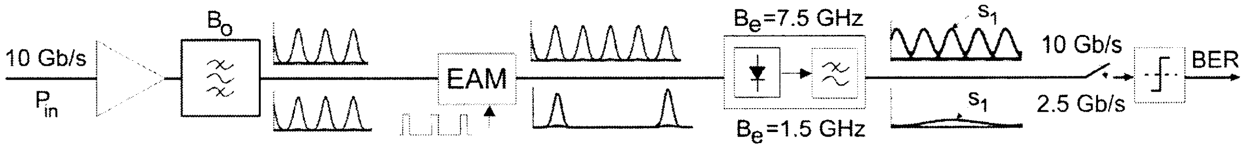

Figure 1: Experimental setup of ETDM receiver and OTDM receiver

Figure 2(a) shows the measured results for an optical bandwidth of B_o=25GHz. Equal performance of all four tributaries was confirmed. The sensitivity difference between the OTDM and the ETDM receiver amounts to about 1dB. Figure 2(b) gives the measured receiver sensitivities at a bit error ratio of BER=10^{-9} as a function of B_o. The 1dB sensitivity difference applies over a wide range of B_o, but can grow up to 3dB for very narrow (15GHz) optical filtering.

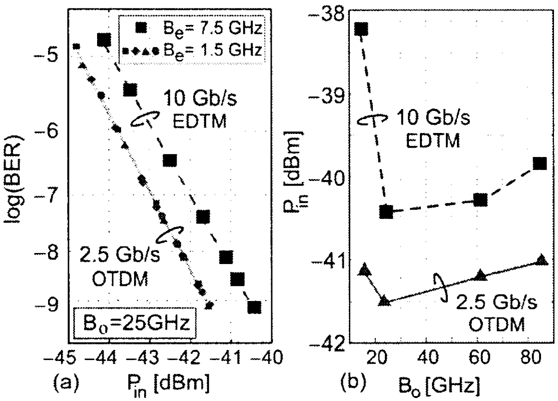

Figure 2: (a) Measured BER vs. input power for 10Gb/s ETDM and 4x2.5Gb/s OTDM; (b) Receiver sensitivity as function of B_o.

Discussion

Due to the high gain of the optical preamplifier, detection noise was dominated by the beating between signal and ASE (σ_1), while noise generated by the receive electronics was negligible. In this beat-noise limited operation, the Q-factor can be approximated as [4]

$$Q \propto \frac{s_1}{\sigma_1} \propto \frac{s_1}{\sqrt{s_1 B_e}} = \sqrt{\frac{s_1}{B_e}} .$$

If the data pulses are short enough to spectrally fill the electrical receiver bandwidth, we find $s_1 \propto B_e$ [5]. The filtered pulse amplitude s_1 thus decreases by the same amount that B_e is reduced when making the transition from an ETDM to an OTDM receiver. Neglecting ISI at the decision gate, this lets the Q-factor become independent of the receiver type. The 1dB improvement that is consistently found in our measurements when going from ETDM to OTDM reception can be explained by taking into account both ISI and an additional noise suppression effect characteristic for OTDM receivers: Fig. 3 shows the Q-factor as a function of the electrical bandwidth for B_o=32GHz, calculated using advanced Gaussian noise formulae [6]. The dotted line represents the *single pulse case* (i.e. the case without ISI). For large B_e the ETDM receiver (dashed line) shows the same performance as the single pulse system, but at B_e<8GHz significant ISI sets in and reduces Q. Since the optical pulses of the 2.5Gb/s OTDM tributaries (thin solid line) are temporally separated by three 10Gb/s-bit slots, ISI plays no role until the electrical bandwidth falls short of ~1.5GHz. Due to the temporal filtering of ASE by the OTDM demultiplexer in combination with the averaging effect brought by narrow electrical filters, the ASE-ASE beat noise is significantly reduced, which further increases Q. This effect is captured by the thick solid line in Fig.3, based on a new, extended noise model for temporal ASE filtering. The enhancement in Q is visualized by the hatched region in Fig.3. For a typical value of B_e=1.5GHz, we find a total difference between OTDM (triangle) and ETDM (square) of about 1dB, in good agreement with our measurements.

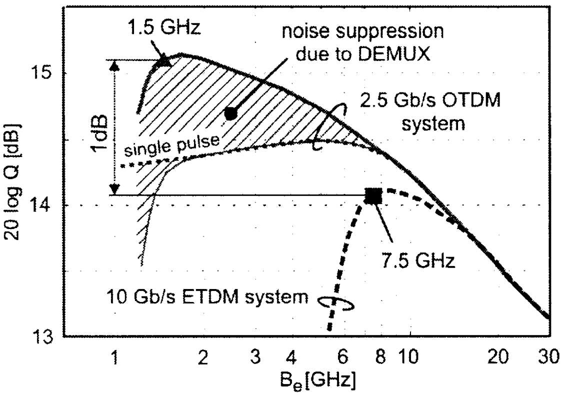

Figure 3: Simulated Q factor as function of electrical bandwidth

Conclusion

Experiments and simulations agree on the similar performance of ETDM and OTDM receivers. Consistent differences between the two receiver types on the order of 1dB can be explained by ISI and an extended noise model, which takes into account the temporal ASE filtering within the OTDM demultiplexer.

References

1 D.Garthe et al., OFC'97 (1997), PD20
2 T.N.Nielsen et al., ECOC'99 (1999), PD2-2
3 Y.Su et al., OFC'02 (2002), ThFF3
4 S.D.Personick, Bell Syst. Tech. J. (1973), 843
5 P.J.Winzer et al., J. Lightwave Techn. (1999), 171
6 P.J.Winzer et al., J. Lightwave Techn. (2001), 1263