Impact of DWDM at 50GHz spacing in the 2µm waveband

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Abstract: In this paper, we show for the first time the impact of decreasing DWDM channel spacing to 50GHz in the 2µm waveband, using 6x12.5Gbit/s and 2x8Gbit/s OOK signals.

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1. Introduction

In an effort to increase capacity and cater for the ever-rising volume of internet traffic, much research in recent years has been dedicated to developing new types of optical fibers, such as multi-core and multi-mode fibers, with record results [1]. However, other types of fibers, specifically hollow-core photonic bandgap fibers (HC-PBGFs), also offer encouraging advantages which warrant investigation. If transmission is shifted from the conventional C-band to the 2µm wavelength range, HC-PBGFs present several promising improvements over standard single-mode fibers (SMFs). These include predicted losses as low as 0.1dB/km [2], up-to 1000-fold potential reduction in nonlinearity [3], and the availability of high-gain, low-noise Thulium-doped fiber amplifiers (TDFAs) which operate over a wide band typically from 1.80µm to 2.10µm [4]. Also, since these improvements involve only-optical components, the electrical infrastructure and advanced modulation formats developed for 1.5µm are still applicable at 2µm [5]. We have previously demonstrated that WDM with 100GHz spacing is possible within this new wavelength region with transmission up to 40Gbit/s [6, 7].

.In this paper, we investigate for the first time the impact of moving to DWDM (dense wavelength division multiplexing), by decreasing the spacing between channels to 50GHz. We show that, while 50GHz spacing can be readily achieved with available components in the transmitter side, there are several challenges associated with the receiver, the most critical of which is the limited extinction ratio of available optical filters.

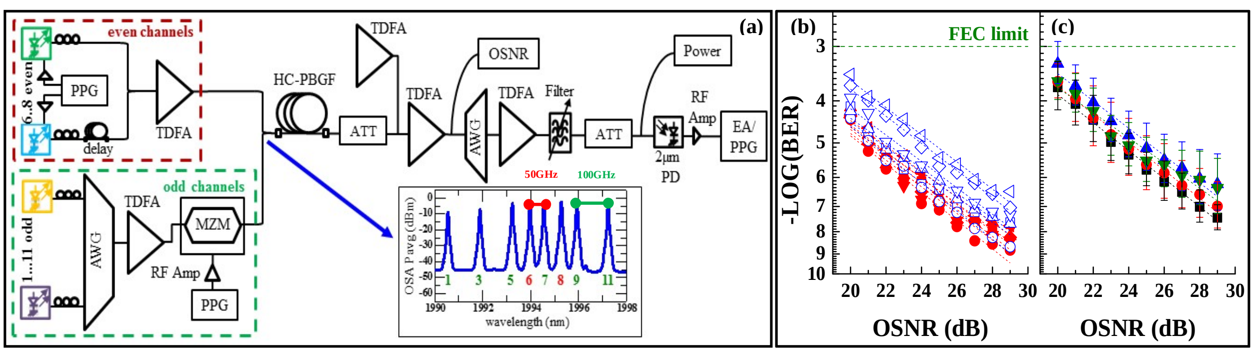

Fig.1 **(a)** Experiment setup. **(inset)** Transmitter spectrum. **(b)** BER vs. ONSR for 100GHz case for back-to-back (closed symbols) & after transmission (open symbols). **(c)** Average measurements for channel #7 cases: single (black), 50GHz (red), 100GHz (blue) & all on (green).

2. Experiment

The experimental setup is depicted in Fig.1(a). The components used were previously described in [6], with the addition of two directly-modulated *even* channels (2x8Gbit/s OOK) and a second arrayed waveguide grating (AWG) to multiplex the *odd* externally-modulated channels (6x12.5Gbit/s OOK). The channel plan is shown in the inset of Fig.1(a), where the *odd* channels (green) were separated by 100GHz from 1990.6 to 1997.3 nm. The lasers used were highly-strained $In_{0.75}Ga_{0.25}As$ multiple-quantum-well, ridge-waveguide laser structures grown on InP substrates and designed for single-mode operation [8]. Polarization controllers were added to ensure co-polarized signals prior to data-encoding. These channels were multiplexed using an InP-based AWG, which was thermally tuned to match the required wavelengths and fixed at 25.6°C. This AWG was fully designed and packaged in-house, with a 10-channel fiber input array to one optical output, and an average insertion loss per channel of 18dB. To compensate for this loss, the output signal was amplified using a TDFA. Non-return-to-zero on-off-keying (NRZ-OOK) modulation was applied using a commercially-available $LiNbO_3$-based Mach-Zehnder modulator (MZM) with a V_π of 9.5V. The MZM was driven by a pseudo-random bit sequence (PRBS) of length 2^{31}-1 at a data rate of 12.5Gbit/s, using an independent pulse pattern generator (PPG) and RF amplifier. To our knowledge, this is the first time such a high baud rate has been demonstrated for closely-spaced OOK channels at 2µm, although higher aggregated bit rates have been achieved with advanced modulation formats and signal processing [6]. In order to achieve 50GHz spacing, two channels (*even*) were added at either side of *odd* channel #7 (at 1994 nm and 1995.3 nm). The lasers added were directly-modulated using a second independent PPG with a PRBS of 2^{31}-1 at a data rate of 8Gbit/s. The bias and drive signals of both lasers were optimized to give sufficient broadening of the laser lines (~0.4nm;10dB bandwidth) in order to investigate the impact of the 50GHz contribution. Also, this ensured that the data from the *odd* channel under test (CUT) was completely de-correlated from the two *even* adjacent channels. The reduced bit-rate was due to the limited frequency response of the lasers, as in [9]. The two *even* channels were then amplified using a commercial TDFA and combined with the six *odd* channels using standard combiners designed for 1.5µm. The eight DWDM signals (inset Fig.1 (a)) were then transmitted through 1.15km of HC-PBGF.

The receiver is also described in [6], although minor modifications were made to ensure sufficient power at the detector for a wide range of Optical-Signal-to-Noise Ratios (OSNRs). Selecting each WDM channel at the receiver is not trivial at 2µm, as currently available tunable band-pass filters have a 3dB bandwidth of ~1.6nm only, and the latest AWG have a side-mode suppression ratio of ~18dB, thus cascading both devices improves channel isolation (at 100GHz spacing) to ~21dB [6]. Here, the filters were swapped to increase the overall OSNR at the detector by ~3dB. In addition, stringent temperature control of the AWG was maintained to accurately align with the CUT. Finally, a noise-load system was added to vary the OSNR in conjunction with the attenuator in the receiver. The power to the detector was maintained at -2.2dBm for all OSNRs.

3. Results

The performance of the DWDM system at 2µm was analyzed in terms of bit error rate (BER) against OSNR. The OSNR was measured as the ratio between the signal and the noise (under the signal) for a 0.05nm bandwidth resolution. Due to the modifications made to the setup, we tested the 100GHz case again (50GHz off) as in [6], and the results are depicted in Fig.1(b). For a BER of $1\text{x}10^{-6}$, an average OSNR of 23.7dB (with a spread of 1.5dB) was recorded for back-to-back and 25.3dB (with a spread of 3.5dB) after transmission over the fiber. The observed average penalty of 1.6dB is consistent with the additional presence of water or CO_2 in the fiber [10]. Nonetheless, all BER results recorded were below the FEC limit of $1\text{x}10^{-3}$. The impact of 50GHz spacing was studied by selecting channel #7 (*odd* channel). In order to allow a fair comparison, this channel was measured as a single channel (DWDM off) initially; then with the two adjacent 50GHz channels on (even on, odd off); with the original 100GHz spacing (odd on, even off); and finally with all (odd and even) channels on. For each case, measurements were repeated five times at back-to-back. The average results are depicted in Fig.1(c). The average OSNR required to achieve a BER of $1\text{x}10^{-6}$ was found to be 25.9dB, 26.5dB, 27.6dB and 27.2dB, respectively. As expected, the results show that the performance of the single channel was better on average, with a higher OSNR requirement for the WDM cases. However, the penalty for introducing the additional channels seems to be minimal. This significantly differs from expectations of much larger OSNR requirement for the worst case (all channels on). We believe this could be attributed to the limited extinction ratio (ER) of the filtering in the receiver. For example, for the 100GHz case (even off), the ER between adjacent channels was ~26dB. This is an improvement from [6], as the AWG in the receiver was thermally fine-tuned to precisely match the CUT, maximizing the OSNR in the receiver, but still not sufficient to completely isolate it, in spite of the use of two cascaded filters. For the 50GHz (odd off) case, the ER was reduced even further to only 10dB, contributing randomly to the BER of the CUT. In addition, the dynamics at the receiver also changed for this case, with a narrower ASE shape under the signal, which may cause less noise beating at the detector. Hence, it is most likely that combination of the compromised ER and ASE variations before the detector caused minimal penalty to be observed between all cases (as in Fig.1(c)).

4. Conclusion

In this paper, we have presented for the first time, the impact of decreasing the spacing of DWDM at the 2 µm waveband to 50GHz, using 6x12.5Gbit/s externally-modulated NRZ-OOK channels combined with 2x8Gbit/s NRZ-OOK directly-modulated channels. We have shown that 50GHz spacing can be readily achieved in the transmitter but improved filtering techniques are required in the receiver in order to accurately analyze the performance of each individual channel.

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5. References

[1] D.J. Richardson et al, Nat. Photon. 7.5, 354-362 (2013)
[2] P.J. Roberts et al, Opt. Express, 13(1), 236244 (2005)
[3] C.M. Smith et al, Nature, 424 (6949), 657-659 (2003)
[4] Z. Li et al, Opt. Express 21, 9289-9297 (2013)
[5] Z. Liu et al, ECOC 2014 (2014)
[6] H. Zhang et al, Opt. Let. 40 (14), 3308-3311 (2015)
[7] M. Sadiq et al, JLT, vol. PP, no.99, pp.1-1 (2015)
[8] R. Phelan et al, PTL 24 (8) pp.652-654 (2012)
[9] N. Mac Suibhne et al, ECOC, paper Th.3.A.3. (2012)
[10] N. Wheeler, et al. CLEO 2012, paper CM3N.5 (2012)