111 Gb/s transmission with compensation of FBG-induced phase ripple enabled by coherent detection and digital signal processing

111 Gb/s Transmission with Compensation of FBG-induced Phase Ripple Enabled by Coherent Detection and Digital Signal Processing

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Abstract *We demonstrate that coherent detection combined with digital signal processing can completely compensate for FBG induced phase-ripple. We report penalty free transmission of 40x111-Gb/s POLMUX-RZ-DQPSK over 1,425-km of SSMF with FBG for in-line dispersion compensation.*

Introduction

Next-generation transmission links are foreseen to operate at line rates of up to 111 Gb/s per wavelength. However, in order to upgrade already deployed networks with 111 Gb/s the modulation format of choice must be at least as robust to all transmission impairments as the currently deployed 10-Gb/s line rates. In particular for low-cost transmission links which use FBGs for in-line dispersion compensation, the upgrade to 40-Gb/s or higher line rates has so far not been possible without a very significant reduction of the maximum system reach [1, 2]. This FBG-induced transmission penalty is due to the ISI generated by phase ripple (PR) impairment in the FBGs. The PR is caused by small fabrication imperfections during manufacturing the FBG [3]. In [4] we showed by means of simulation that the penalty from the FBG-induced PR can be compensated for by using coherent detection in combination with digital equalization. In this paper, we try to prove the results of [4] experimentally for 111-Gb/s polarization multiplexed, return to zero, DQPSK (POLMUX-RZ-DQPSK) both at back-to-back configuration and in case when FBGs are used in a transmission link for dispersion compensation.

Compensation of Phase-Ripples at Back-to-Back

The penalty for a coherent receiver as a result of FBG-induced PRs is investigated in this section by comparing the performance of an FBG cascade to a DCF cascade with an equivalent amount of chromatic dispersion. The experimental setup of this measurement is shown in Fig. 1. A POLMUX-RZ-DQPSK signal is generated by modulating the output of an ECL laser using the transmitter described in [5]. After the transmitter, 12-FBG modules with a total CD of -14,600 ps/nm are cascaded in order to generate strong PR accumulation. For this experiment un-channelized, C-band, chirped FBGs are used, that are manufactured by Proximion. At the receiver, a variable optical attenuator (VOA) and EDFA amplifier are used to control the optical signal to noise ratio (OSNR) of the signal. Finally the signal is detected with a coherent receiver. A full description of the coherent receiver and off-line processing algorithms can be found in [5]. In order to have more statistical results from offline-processing, each measurement point consists of the average of 5 sets of data that are recorded with a time interval of 30 sec.

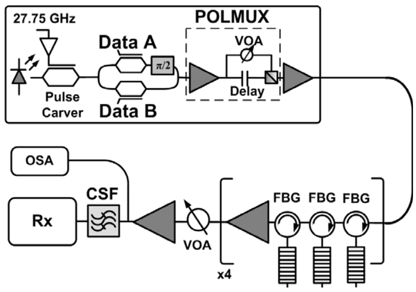

Fig. 1: Experimental setup,

The ECL laser at the transmitter side is swept over 40 channels in the C-band (the channels between 1542.5 nm and 1558.2 nm), and for each channel the required OSNR for a BER of 10^{-3} is calculated. For comparison purposes, three measurements have been carried out. The first measurement is a reference measurement with no modules installed between the transmitter and the receiver (B2B). For the second measurement, 12 FBG modules are inserted between the transmitter and the receiver. Finally, in the third measurement, DCF modules are inserted with the same amount of accumulated CD as in the case of FBGs. Frequency domain equalizer (FDE) based on the linear Schrodinger equation is used at the receiver to compensate for the bulk CD from the FBG /or/ DCF modules. Fig. 2 shows the results of the three measurements for the 40-WDM channels. For the case when FBGs are used for dispersion compensation, the ISI in the signal cased by the PRs is easily compensated by the FIR equalizer in the coherent receiver, and therefore no difference in required OSNR between the different channels is observed. The FIR filter has 13 taps at T/2 spacing, which gives it the ability to equalize the ISI cause by very large amounts of PRs. Comparing now the results of both the FBG and DCF modules in Fig. 2, a similar performance is observed, which again confirms that no additional penalty is introduced by PR of the FBGs. Compared to the B2B configuration,

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the required OSNR is increased by about 1 dB for the configurations with DCF /or/ FBG modules. This additional penalty is most likely caused by the FDE algorithm.

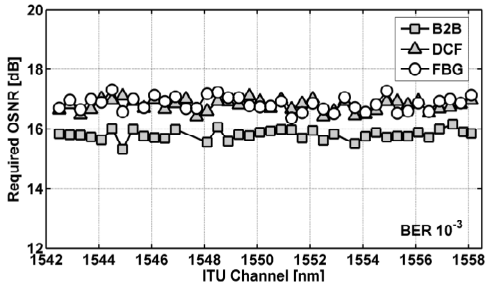

Fig. 2: R*esults of 40 channels with coherent detection*

In [1], it has been shown that in case of using FBGs with 40 Gb/s DPSK signals, even a small detuning for the channel frequency can results in a significant penalty. This is due to the random distribution for the PRs even within each of the ITU channels. To verify that such a frequency drift does not lead to any penalty for our 111-Gb/s POLMUX-RZ-DQPSK signal, a fine scanning in a range of ±10 GHz from the 1550.52 channel is performed with steps of 1 GHz. Fig. 3 shows the required OSNR for a BER of 10^{-3} as a function of the ITU frequency offset. This shows that even for significant frequency offset no PR penalty can be observed.

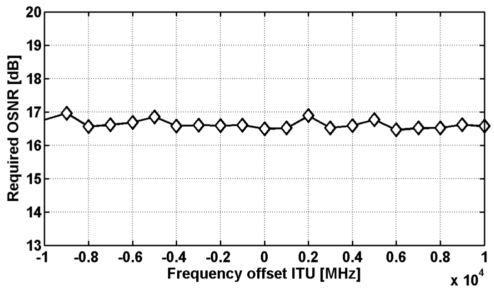

Fig. 3: Results of the ± 10 GHz scan around 1550.52 nm

Transmission with in-line FBGs

In this section the transmission penalty of FBG induced PRs is investigated for the 111-Gb/s POLMUX-RZ-DQPSK signal with coherent detection. For this purpose, 40x111 Gb/s POLMUX-RZ-DQPSK channels are generated using two parallel transmitters for odd and even channels (see [6]). To generate the 40-channels, 40 distributed feedback lasers (DFB), tuned to the 50-GHz ITU grid between 1542.5 nm and 1558.2 nm are used. The re-circulating loop used for transmission, consists of 5x95 km SSMF spans with an average CD of 16.8 ps/nm/km (Fig. 4). For comparison purposes, (1) FBG or (2) DCF module is used for CD compensation after each span, or (3) no optical CD compensation is used and the total accumulated CD is compensated for by the FDE equalizer in the receiver side. The signal propagates 3 times around the re-circulating loop, resulting in a total transmission distance of 1,425 km. At the receiver side, a channel selective filter (CSF) is used to extract the channel under test, which is then input into the coherent receiver [5].

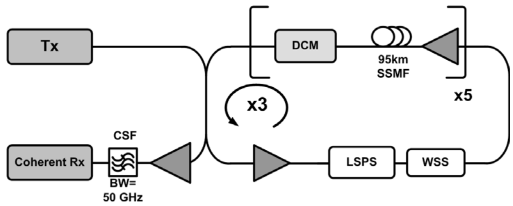

Fig. 4: Setup of transmission system

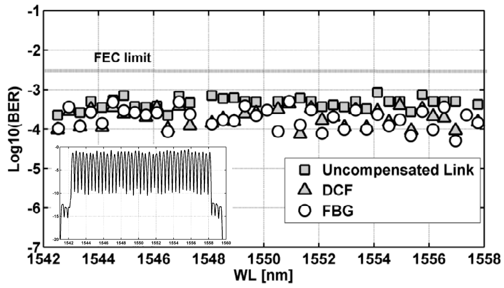

Fig. 5: Transmission results for 40-channels in C-band, spectrum of 40 channels is shown in the inset

Fig. 5 shows the BER performance of the 40 channels using either FBGs, DCFs or the uncompensated link. Note that in the case of the transmission loop effectively the total number of cascaded FBGs is 15, as each FBG is passed for 3 times. In this case, it is expected to have stronger effect for PRs, as we have correlated PRs now by passing each FBGs for three times. However, one can notice in Fig. 5 almost no difference in performance between the 40 channels under test. Moreover, practically no difference in transmission performance is observed between DCF and FBG. Only a minor difference is noticed between the results of FBG and the uncompensated link. We conjecture that this difference is caused by the penalty obtained from the un-optimized FDE for the uncompensated link.

Conclusions

In this paper, we experimentally demonstrate that the phase ripples of FBG can be compensated for using coherent detection in combination with DSP. No additional penalty due to phase ripples was observed when comparing the performance of FBGs to that of DCF. This enables the use of 111-Gb/s POLMUX-RZ-DQPSK signals over currently depolyed links that use FBGs for in-line dispersion compensation.

References

1. D. van den Borne, et al., PTL Volume 19, Issue 14, July 2007 pp1069 – 1071.
2. H. Bissessur, et al., OFC 2005 paper OFN4.
3. C. Scheerer, et al., ECOC 1999, pp. I-410.
4. V. Veljanovski et al., OFC 2009, paper JThA40.
5. C.R.S Fludger, et al., JLT 2008, 26(1), pp. 64-72.
6. M. S. Alfiad, et al., OFC 2009, paper OThR4.