Demonstration of 1000km 43Gb/s RZ-DPSK Transmission through a 50GHz Channel Spaced WSS

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Abstract: We demonstrate bandwidth-limited 1000km transmission of 43Gb/s RZ-DPSK signals. System bandwidth was limited via a MEMS-based wavelength-selective switch operating at 50GHz channel spacing. The system demonstrates increased tolerance to bandwidth limitation, noise and non-linearity.

OCIS Codes: (060.2340) Fiber optics components, (060.2360) Fiber optics links and subsystems

1. Introduction

Deployment of 40Gb/s systems is constrained by multiple physical effects and design considerations. System reach can be improved using advanced modulation formats to increase the tolerance to noise and non-linear effects, but at the same time, the bandwidth requirements of these modulation formats may increase. As bandwidth requirements increase, the system design considerations may limit the use of filter cascades and denser channel spacing. Furthermore, it is highly desired, especially in 40Gb/s systems, to use dispersion compensation modules (Bragg gratings, etalon, virtual imaged phase-arrays, etc.) rather than dispersion compensation fibers (DCFs) since they exhibit lower insertion loss and reduce non-linear effects. For network flexibility, it is also desired to use reconfigurable-add/drop modules (ROADMs), which limit the system bandwidth. Multiple cascades of DCMs and ROADMs along with the desired move from 100GHz to 50GHz channel spacing create a considerable design constraint on high bandwidth transmission systems.

In order to tackle system bandwidth limitations, bandwidth-tolerant modulation formats such as doubinary and DQPSK were evaluated [1-4]. In doubinary transmission, the noise tolerance is comparable to NRZ and the non-linear threshold is also similar to NRZ [5]. DQPSK is a promising solution, but is not cost effective. In contrast, RZ-DPSK is cost effective and has many advantages over NRZ with higher noise tolerance and non-linear threshold [6].

Some studies were conducted to determine the ability of operating 40Gbps RZ-DPSK signals at 50GHz spacing [7]. We demonstrate the feasibility of a reconfigurable 43Gb/s RZ-DPSK system that compromises some of the noise tolerance to overcome some of the bandwidth limitations of 50GHz spaced systems. A 1000km link was tested with error-free post-FEC transmission down to 16dB OSNR. In the linear regime, the system margin was measured to be 3dBQ at 19dB OSNR.

2. Experimental Setup of 1000km

Fig. 1 shows the experimental setup of the 1000km link. The RZ-DPSK transmitter includes two modulators, one for phase modulation of the data and one for amplitude modulation of the clock for RZ pulse carving. The resulting RZ-DPSK signal is transmitted through the system which consists of 10 spans of 100km of G.652 and mid-stage access optical amplifiers. The dispersion compensation is inserted in the mid-stage access of each amplifier and the resulting dispersion map can be seen in Figure 1. In order to minimize the non-linear penalty, we inserted dispersion pre-compensation of about 1360ps/nm.

The optical amplifiers are of various qualities and the spans include extra attenuation to emulate deployable margins; therefore, we plotted the overall span loss plus the noise figure (S+NF) for each span. The typical noise figure value of such an amplifier at 22dB gain is about 6.5dB, which is the case for the first 5 amplifiers (S+NF=28.5dB). Since we used lower quality amplifiers for the last 5 links, the S+NF value for these spans is about

33-34dB. The average S+NF value for the 10 spans is about 31.5dB, reflecting an average link budget of 25dB when using typical mid-stage amplifiers with 6.5dB noise figure in every span.

The signal is filtered using a 50GHz WSS; the spectrum before and after can be seen in the bottom right of the Figure. The filtered DPSK signal is demodulated using an asymmetric mach-zender demodulator and received into a differential receiver.

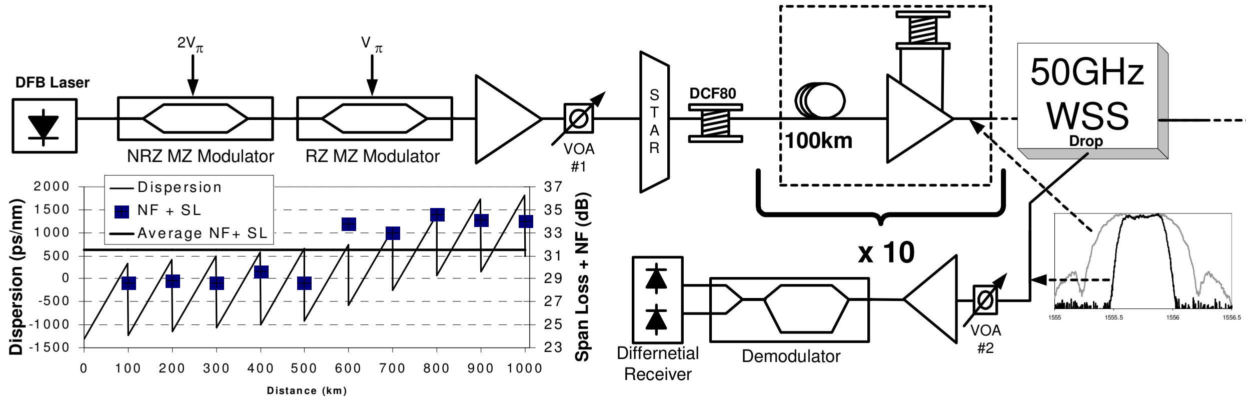

Fig. 1. Experimental trial setup and dispersion map

3. Results and Discussion

Fig. 2 shows the transfer function of the 50GHz wavelength-selective switch (WSS) based ROADM. The passband and ripple in this case was measured using a tunable laser [8]. As one can see, the 1dB passband of the WSS was measured to be 282pm with negligible dispersion and phase ripple in this region. This filter, although operating at 50GHz spacing, has a wide operation bandwidth thus allows for greater bandwidth efficiency and minimal signal degradation of the 40Gbps signals.

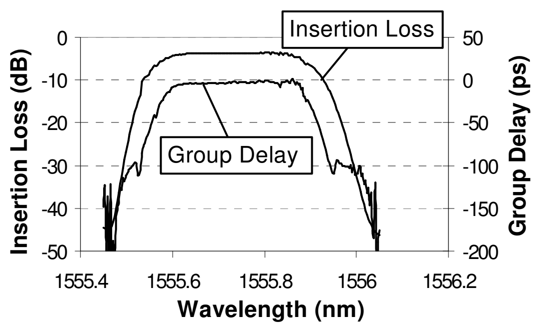

Fig. 2: WSS insertion loss and group delay

The transmission is limited by self-phase modulation (SPM); the required OSNR as a function of launch power for error-free post-FEC transmission can be seen Fig 3(a) for single-span and Fig. 3(b) for 10 spans. In the linear region, the required OSNR for both experiments is similar. The single span OSNR performance is about 13.5dB using a 100GHz spaced filter, and incurs a 1.5dB penalty when the filter is exchanged with the 50GHz WSS.

As seen from Fig. 3, showing a minimum required OSNR to achieve error-free performance after FEC vs the signal launch power into the fiber, the 1dB SPM threshold in the single-span experiment is about 16.5dBm, while for the 10-span experiment, the threshold is decreased to 6dBm. Therefore, the design rule (Pmax model) for the non-linear threshold in this case is 16dBm-10*log*N [9], where N is the number of spans. This demonstrates a 4dB improvement over the NRZ case, similar to [6]. Note also that the SPM threshold is filter type independent since the filter is placed at the output of transmission.

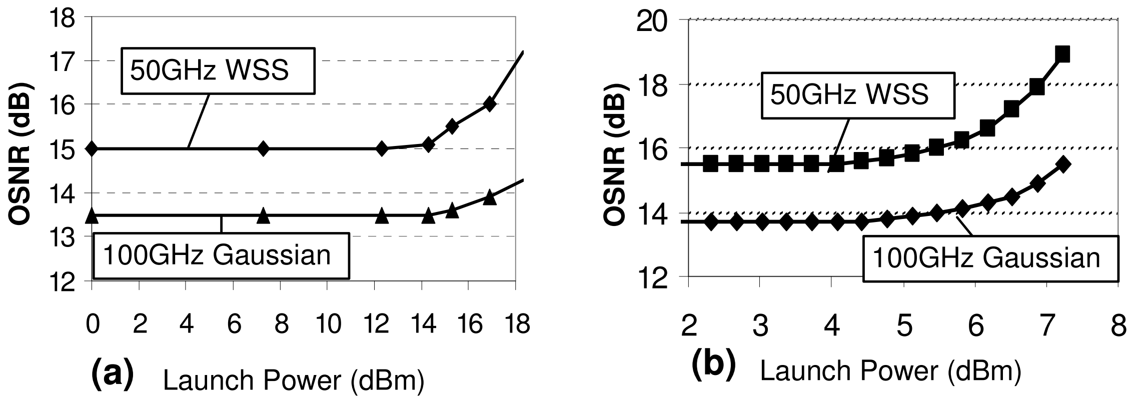

Fig. 3: Non-linear induced SPM threshold for (a) single span, and (b) 10 spans, 1000km. Figure shows a minimum required OSNR for error-free post-FEC performance vs optical power launched into the fiber.

Fig. 4 (a) and (b) show the pre-FEC bit error rate (BER) for 800km and 1000km experiments respectively. The optimal launch power per span is around 4dBm in both cases. As one can see, the 50GHz channel spacing system launch power can range from –2.5dBm to 7dBm for the 800km experiment, and –1dBm to 7dBm for the 1000km experiment. This corresponds to about 4.2dBQ and 3dBQ margin for the 800km and 1000km experiments, respectively.

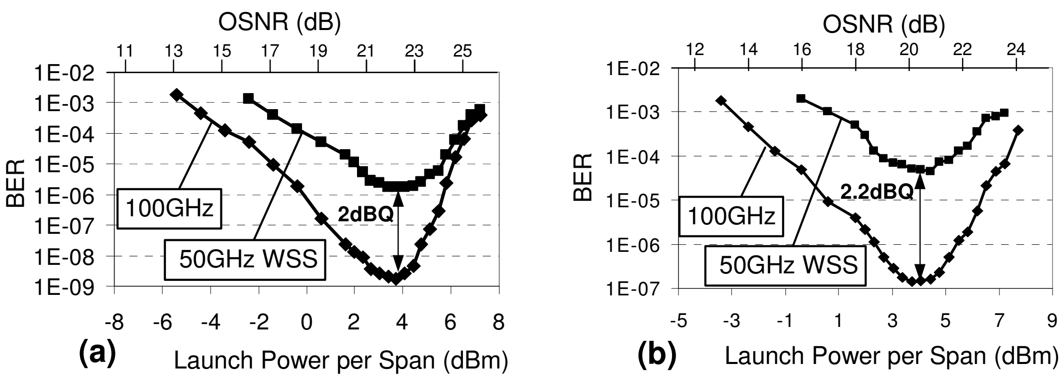

Fig. 4 Test results after a) 800km and b) after 1000km

As seen in Fig. 4, when the filter bandwidth is reduced from 100GHz to 50GHz channel spacing, the signal degradation was measured to be 2dBQ and 2.2dBQ in the 800km and 1000km experiment, respectively.

4. Conclusions

We demonstrated the feasibility of a 40Gbps RZ-DPSK, WSS-reconfigurable transmission system operating at 50GHz spacing. The system showed 3dBQ margin with 19dB OSNR after 1000km. The span loss plus the amplifiers' noise figure were elevated in the experiments to 31.5dB. We measured error-free post-FEC transmission of 13.5dB OSNR with a 100GHz channel spaced filter and 15dB with the 50GHz channel spaced WSS ROADM. The post-FEC SPM threshold of the RZ-DPSK system was independent of the filter type and measured around 16.5dBm for a single span and 6dBm for 10 spans, demonstrating a 4dB improvement over NRZ. This transmission link takes advantage of the high non-linear threshold and high OSNR tolerance of RZ-DPSK, while compromising some of its performance to accommodate bandwidth-limiting effects of 50GHz channel spaced transmission. The system can be further improved by using a filter-tolerant partial DPSK modulation format (P-DPSK) described in [10].

5. References

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