PHASE AND AMPLITUDE MODULATION FORMATS FOR HYBRID 40GB/S AND 10GB/S DWDM PHOTONIC LONG-HAUL TRANSMISSION

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ABSTRACT

Amplitude and phase shift keying modulation and pulse sequence formats are employed to demonstrate their effectiveness in optical fibre transmission systems at a bit rate of 40Gb/s over the dense wavelength multiplexed 10Gb/s channels. The impacts of optical filters are studied for 40Gb/s 320 km standard single mode optical fibre optically amplified and dispersion compensated transmission system employing RZ/ NRZ/CS-RZ amplitude shift keying and differential phase shift keying modulation formats. For 0.5 nm passband multiplexers and demultiplexers for wavelength channels multiplexing and separation, the receiver sensitivities are insignificantly affected.

1. INTRODUCTION

Upgrading existing fiber communications backbone infrastructure is very important in the near future. One of the possibilities is selectively increasing the transmission rate 40 Gb/s over the existing 10G return to zero (RZ) format dense multi-wavelength (DWDM) optical communications systems. Due to the properties of the installed fibre, the transmission methods must be chromatic-dispersion (CD) and polarization-mode dispersion (PMD) tolerant. This favors the use of advanced modulation formats (such as variants of phase-shift-keying) rather than ultra-high-rate time division-multiplexed (TDM) schemes, because the effects of CD and second-order PMD are proportional to bit-rate-squared. However there are various *optical filters* installed throughout the DWM optical transmission systems such as optical multiplexers (mux), demultiplexers (demux) and add-drop muxes that would affect the spectral properties of the multiplexed channels, particularly when a hybrid transmission of 10Gb/s and 40Gb/s channels. Recently advanced modulation formats are considered to play a significant role in enhancing the effectiveness of bandwidth reduction and effective transmission over long distance [1], [2] This paper investigates the transmission of 40 Gb/s channels over 10Gb/s DWDM optical system in which 'standard' optical filters employed for 10 Gb/s systems are used. Differential phase shift keying (DPSK) and quadrature phase shift keying (DQPSK) modulated lightwave channels are co-transmitted and compared with those employing RZ- and NRZ amplitude shift keying (ASK). We demonstrate that with the passband of optical filters in order of 0.5 nm the transmitted 40Gb/s channels are not penalized and vice versa for 10 Gb/s DWDM channels. Transmission BER and receiver sensitivities are reported for different transmission scenario.

2. OPTICAL TRANSMISSION SYSTEM SET-UP AND PERFORMANCE

The optically amplified fibre transmission set up is shown in Fig. 1. A tunable laser source is coupled with the SHF-5003 optical transmitter to modulate lightwave channels. Various formats such as RZ, Carrier suppressed RZ, NRZ, RZ-DPSK, RZ-DQPSK can be generated. Array waveguide gratings with ITU- standard wavelength grids are inserted at the transmitter and receiver sites. Optical amplifiers as pre-amplification-sub-systems and booster are employed at the front and post end, respectively of dispersion compensating modules (DCM) to compensate for transmission and compensating fibre losses and boosting the power of optical channels so as to keep the transmission system uniform over the pans of the transmission link. Differential or intensity receivers are used at the receiving end before inserted to the error analyzer. The average optical power is measured via coupling 1:10 coupler at the input of the receiver. Thus all optical receiver sensitivity must be increased accordingly. The transmitter consists of two cascaded interferometric optical modulators. One serves as the pulse carver and the other for data switching. A CSRZ format can thus be created by biasing the pulse carver at its minimum transmission point. If it is biased at maximum transmission the generated data sequence would operate at a carrier-max state. DPSK and DQPSK formats can also be generated by integrating an electrical pre-coder and then amplified to an appropriate level so as to swing the data pulses over the biasing state with a phase difference of 0 and π. The spectra of ASK and DPSK optically modulated signals for transmission are shown in Fig. 2. An optical attenuator is used to adjust the optical power entering the receiver to evaluate the receiver sensitivity. Several types of optical filters are inserted such as NEL AWG mux/demux filter with a 0.45 nm 3 dB bandwidth (BW) and 100 GHz spacing (ii) Piri AWG mux/demux filter 0.5 nm (3dB bandwidth) - 200 GHz spacing (iii) FBG of 0.55 nm passband (iv) AWG 8 Channel Demux – 0.35 nm passband (v) JDS tunable filter of 1.3 nm passband (vi) Santec 0.5 nm BW – wideband roll off which are inserted into the transmission system wherever appropriate.

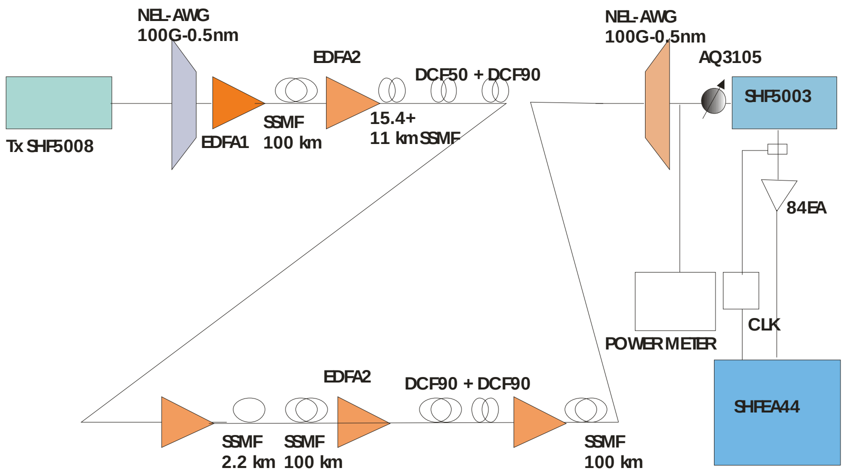
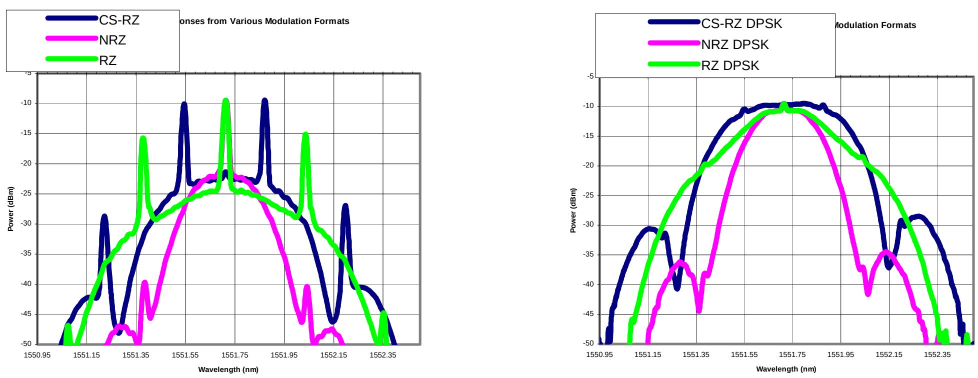


Fig. 1. System configuration of the photonic transmission system for 40Gb/s CS-RZ DPSK, NRZ DPSK and RZ DPSK – base rate 40 Gb/s.

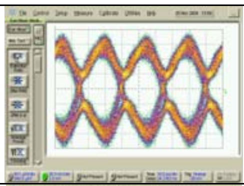
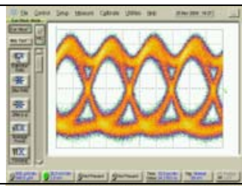
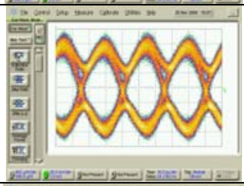
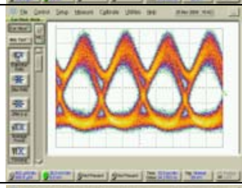
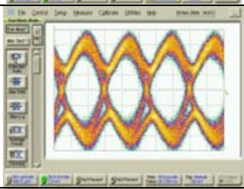
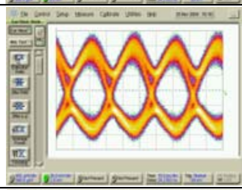
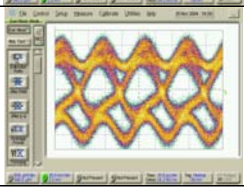
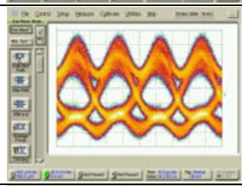
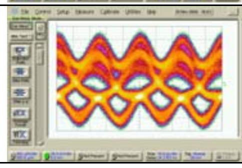


(a) (b)

Fig. 2. Optical spectra of 40Gb/s CS-RZ, NRZ DPSK and Rz (a) ASK; (b) DPSK modulated signals

Typical eye diagrams detected of the differential phase shift keying formats are demonstrated in Table 1. Decision threshold can be set at an optimum level to achieve the best bit-error rate that can be measured by an error analyzer SHF 44EA. The transmission distance is set so that the dispersion tolerance of the transmission formats can be characterized. Thus the back to back and up to 4 km transmission through various distance of standard single mode optical fibres can be achieved.

Table 1. Detected eye diagrams of differential phase modulation with formats RZ and carrier suppressed RZ.

Transmission distance without dispersion compensation	**RZ DPSK**	**Carrier suppressed DPSK**
Back to back		
1 km Standard Single Mode Fibre (SSMF) Dispersion factor +17 ps/nm.km		
2 km SSMF		
3 km SSMF		
4 km SSMF		

Initially the impacts of the optical filtering characteristics of the mux are evaluated with back to back transmission set up. The sampling clock is set directly from the auxiliary clock output of the 2^{31}-1 pattern generator. Although two AWGs can be used as muxes and demuxes we use only one AWG at either the transmitter or receiver sites. The other filter can be substituted by a thin-film multilayer optical filter. Two optical filters acting as mux and demux at the transmitting and receiving ends are then used to evaluate their impacts on 40 Gb/s channels. We observe insignificant degradation of the BER as shown in Fig. 3. Note that the sensitivity must read 10 down from the scale given in these figures due to the coupling 1:10 ratio.

The BER versus the receiver sensitivity curves are obtained for ASK and DPSK and DQPSK with RZ, NRZ or CSRZ formats are shown in Fig. 3. The sensitivities do not change significantly under the influence of the 0.5 nm optical filter on 40 Gb/s channels operating under different modulation formats. The Gaussian-like or $\cos^2$ profile of the pulses generated at the output of both optical modulators and the parabolic passband properties of the AWG can tolerate wider signal spectra. We do not observe any degradation of the BER versus the sensitivity for the cases of wideband optical filters (1.2 nm) and 0.5 nm optical mux filtering.

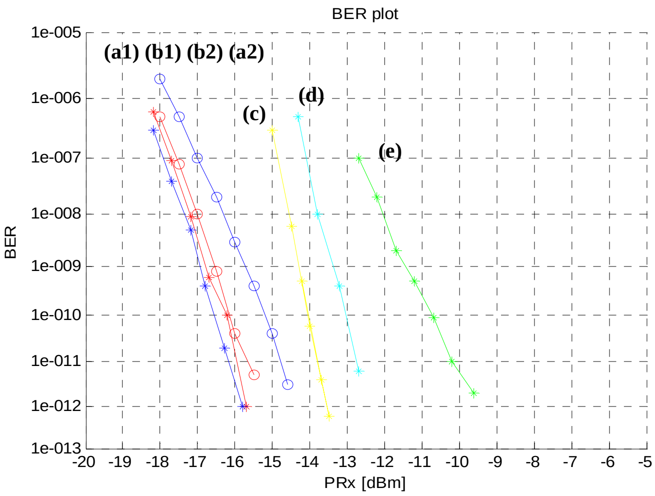


Fig. 3. Optical filtering effects with BER versus received optical power (at the power meter – 1:10 coupler before Rx). Legends: (a1) *"blue-*"* - CSRZ-DPSK (one NELAWG); (b1) *"red -*"* - RZ DPSK(one NELAWG); (b2)*"Red-o"* - CSRZ DPSK two AWGs; (a2)*"blue-o"* - RZ-DPSK with two AWGs; (c) *"yellow"* - CSRZ- ASK (one NELAWG); (d) *"cygan"*- RZ-ASK(one NELAWG); (e) *"green"* - NRZ ASK(one NELAWG)

The transmission is then conducted with the total transmission length of the standard single mode fibre (SSMF) of 320 km and an effective dispersion compensating length of 328 km. That means that an effective 8 km SSMF mismatch of dispersion in the 1550 nm spectral window. The BER versus the receiver sensitivity for CSRZ-DPSK and RZ DPSK formats is obtained as shown in Fig. 4 curves (a) and (b) respectively. The optical filters used as muxes have a typical passband of 1.2 nm and 0.5 nm. No degradation of the receiver sensitivity is observed for different passband filters. A 4 dB improvement on the receiver sensitivity is observed for CS-RZ DPSK over that of RZ-DPSK due to an enhancement in the total energy contained in the pulse sequence with a suppression of the carrier of the CS-RZ DPSK.

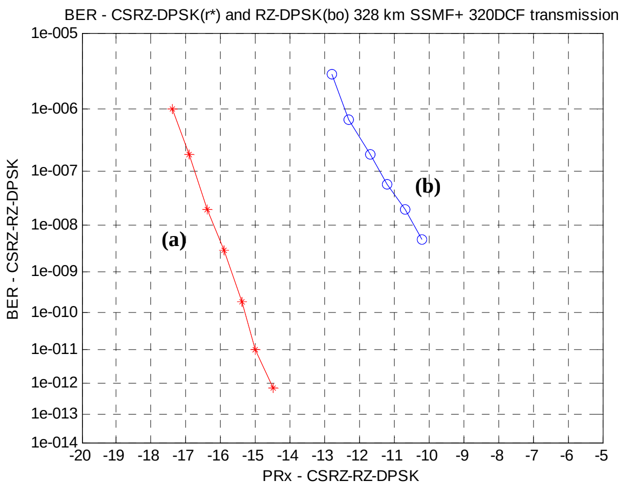


Fig. 4. Transmission system: 328 km SSMF + DCM320 compensating fibres with (a) CSRZ-DPSK and (b) RZ-DPSK modulated signals. Notes: the mux is NEL AWG 0.5 nm 100 GHz spacing and demux is 1.2 nm thin film optical filter.

3. IMPACT OF ADJACENT 10G/40G CHANNELS

The 320km transmission is also conducted to assess the performance of 10G NRZ ASK and a CS-RZ DPSK 40G channel. The set up of the transmission system with 320km SSMF and dispersion compensating modules with two 100GHz AWG's used as mux and demux filter to measure the impact of adjacent CS-RZ DPSK 40G channel on 10G NRZ-ASK performance. No significant impact on 10Gb/s signal is noted when 40G channel, adjacent or non-adjacent, is co-transmitted as evaluated in Fig. 5

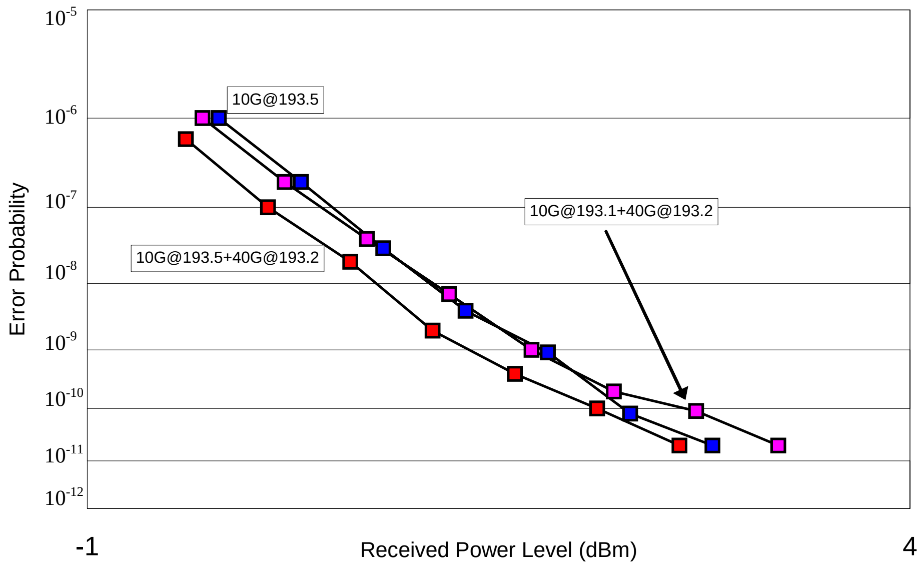


Fig. 5. 320 km transmission 40 G impact on 10G channel: BER versus receiver sensitivity (dBm)- effects of 40 G (CS_RZ DPSK) with 10G (NRZ-ASK) channel simultaneously transmitted for NRZ ASK and CS-RZ DPSK formats

4. CONCLUDING REMARKS

We have demonstrated that the transmission of 40 Gb/s channels over an optical fibre communication system whose optical characteristics are similar to those of standard 10 Gb/s. The filtering properties of the muxes and demuxes do not affect significantly the transmission performance in term of BER and receiver sensitivity. We have also measured the transmission quality of both 40 Gb/s and 10 Gb/s channels and observe no degradation of either channels by the other. Indeed the use of optical filters can also be incorporated with the frequency discrimination technique for phase detection of DPSK channels [4]. In this case a narrow band optical filter will reduce the amplified noises and simplify the receiver structure.

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