ULTRA LONG-HAUL AND HIGH-CAPACITY 40 GBPS DWDM TRANSMISSION SYSTEMS OVER TRANS-PACIFIC DISTANCE

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Abstract: This paper describes our study results toward deployment of 40Gbps DWDM long-haul submarine cable systems. We have first studied both RZ-DPSK and RZ-DQPSK modulation formats theoretically and experimentally. For the trans-Pacific reach beyond the above limitation, we have been investigating the best modulation among various multi-level modulation formats, including combined use of polarization multiplexing and coherent detection.

1. INTRODUCTION

The terrestrial systems have already implemented 40Gbps technology. As a natural consequence, the submarine systems will soon or later switch to 40Gbps not only for its higher-capacity transmission capability but also for seamless connection between them. Although the 40Gbps system based on multi-level modulation is shown to achieve much higher capacity and spectral efficiency compared with the current 10Gbps systems, much effort should be paid to enable long-haul transmission over trans-Pacific distances.

This paper describes our study results toward deployment of 40Gbps DWDM long-haul submarine cable systems. We have first studied both Return to Zero Differential Phase Shift Keying (RZ-DPSK) [1-3] and Return to Zero Differential Quadrature Phase Shift Keying (RZ-DQPSK) [4] modulation formats theoretically and experimentally. It is found from simulations that, the maximum transmissible distance under optimum conditions is limited up to approximately 6,000 km with RZ-DPSK signals and 5,000 km with RZ-DQPSK signals respectively, if we consider adequate system margins during 25 years of operation. For the trans-Pacific reach beyond the above limitation, we will discuss the best choice of the modulation among various multi-level modulation formats, including combined use of polarization multiplexing and coherent detection[5, 6] by focusing on the optical SNR tolerance, spectral efficiency and non-linear endurance. .

2. PERFORMANCE COMPARISON WITH RZ-DPSK AND RZ-DQPSK SIGNAL

RZ-DPSK and RZ-DQPSK modulations are one of the competitive and practical candidates for submarine 40Gbps cable transmission systems due to not only its excellent transmission performance, but also good compatibility with conventional 10Gbps systems and high technology maturity and general availability. So, it is still an important issue to make clear its transmissible distance under the optimized dispersion map and its applicability to submarine cable systems.

Firstly, we have conducted simulations to investigate the optimal performance of 43Gbps RZ-DPSK and RZ-DQPSK signals transmission over 6500km assuming the EDFA repeatered DMF transmission line.

2.1 Dispersion Map Optimization

For designing the transmission line configuration for long haul transmission systems, the dispersion map needs to be adequately balanced where the nonlinear interaction induced by SPM, XPM and FWM is minimized.

Figure 1 and Table 1 show a basic configuration of the Dispersion Managed Fiber (DMF) transmission line and simulation parameters assumed in our simulation study. Span averaged dispersion of DMF is set to -2.5 ps/nm/km. Block averaged dispersion is adjusted by a block Dispersion Compensation Fiber (DCF) allocated in every ten spans. The ensemble transmission line can be configured by the concatenation of this basic line configuration. In our simulations, the block average dispersion is swept for optimal dispersion map for 43 Gbps DWDM transmissions. In order to make the simulation closer to the real system performance, the parameters of transmitters, the receivers and optical Mux, DMux filter characteristics are calibrated based on the measurement data, commercial component parameters.

Figure 2 shows a block averaged dispersion dependency of received Q value after 6500km transmission for 100GHz spaced RZ-DPSK signals and 50GHz spaced RZ-DQPSK signals respectively.
The Q factors for RZ-DPSK and RZ-DQPSK show a peak at block average dispersion of around +0.2ps/nm/km.
According to this results, smaller block averaged dispersion setting seems to be effective both for 40Gbps RZ-DPSK and RZ-DQSPK signal transmission, compared to that of 10Gbps RZ-DPSK systems.

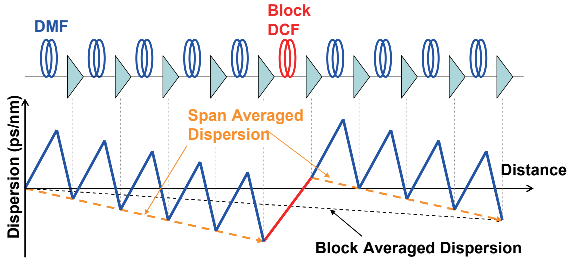


Figure 1: DMF Block Configuration

Table 1: Simulation Parameter

Bit-rate	43 Gbps
Modulation	RZ-DPSK RZ-DQPSK
Channel Spacing	100GHz at RZ-DPSK 50 GHz at RZ-DQPSK
Span Length	50 km
Repeater	EDFA
Output Power	-4 dBm/ch
Noise Figure	4.5 dB
Distance	6500 km

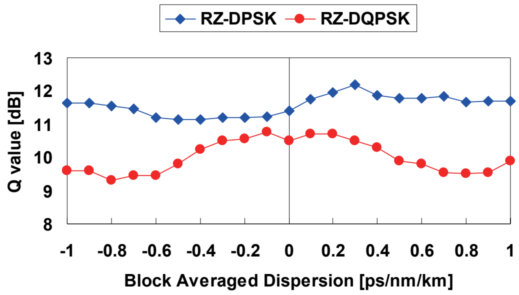
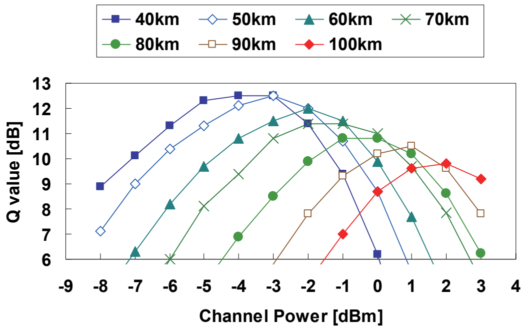


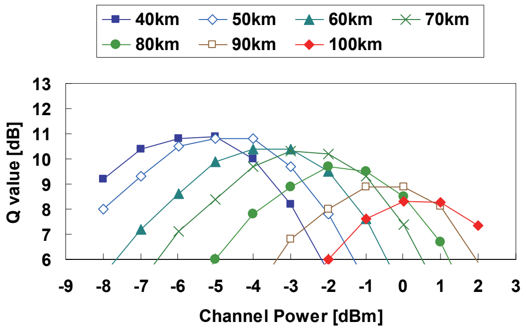
Figure 2: Block Averaged Dispersion Dependency

2.2 Channel Power Optimization at Different Span Length

Based on the above dispersion map optimization results, we evaluate the channel power optimization under different span length settings. Figure 3 shows the simulation results on system optimization under different span lengths and channel power for the 100GHz spaced RZ-DPSK and 50GHz spaced RZ-DQPSK signals respectively. As is clearly shown in this figure, optimal channel powers are decreasing according to the span length reduction. Therefore, it is important to select the best combination of the span length and channel power setting to maximize the transmission performance. If we consider system margins of around 3dB over commercial FEC limit during 25 years of operation, transmissible distance with 100GHz spaced RZ-DPSK signals can reach up to 6,500km with less than 60 km span length. However, in the case of RZ-DQPSK, the maximal Q value is less than 12 dB, which indicates that DWDM submarine systems with 50GHz spaced RZ-DQPSK signals is technically sound for systems up to around 5,000 km.



(a) 100GHz spaced RZ-DPSK



(b) 50GHz spaced RZ-DQPSK

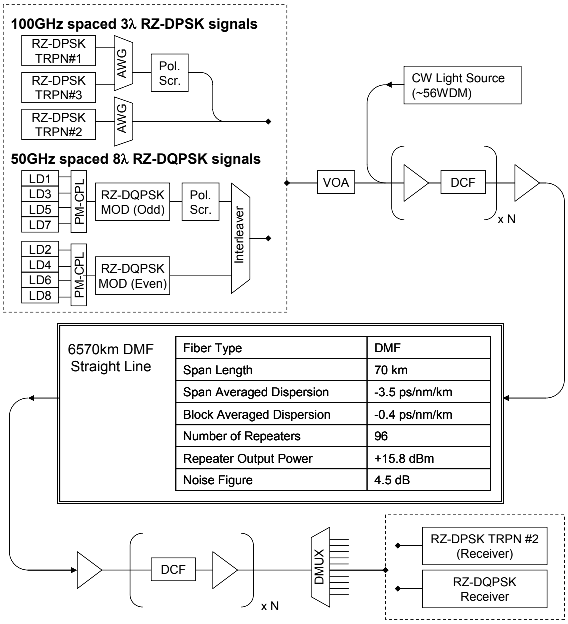
Figure 3: Channel Power Dependency at different span lengths

3. 6,570KM STRAIGHT DMF LINE TRANSMISSION WITH RZ-DPSK AND RZ-DQPSK SIGNALS

In order to confirm the validity of numerical estimation and evaluate the actual system performance, we conducted the transmission experiments of 100GHz spaced RZ-DPSK signals and 50GHz spaced RZ-DQPSK signals respectively, by using 6570km straight DMF transmission line.

3.1 Experimental Setup

Figure 4 shows an experimental setup for the 100GHz spaced RZ-DPSK and 50GHz spaced RZ-DQPSK signal transmission. For RZ-DPSK signal evaluation, three 43Gbps RZ-DPSK transponders are used and these wavelengths are allocated with 100GHz spacing. Center channel and neighboring channels are separately multiplexed by AWG. Then, these channels are multiplexed by optical coupler. For RZ-DQPSK signal evaluation, transmitter is composed with 8 DFB-LDs equally spaced at 50 GHz intervals. Odd and Even channels were separately modulated into 43Gbps RZ-DQPSK signals by two 43Gbps RZ-DQPSK modulators. The odd and even channels are multiplexed by a 50/100 GHz interleaver. Modulated signals are multiplexed with 56CW light sources and then inserted to pre-DCF. The parameters of DMF transmission line is also depicted in the Figure 4. In this experiment, span averaged dispersion of -3.5 ps/nm/km and block averaged dispersion of -0.4 ps/nm/km are used. In the receiver end, after post-DCF, measured channel are selected by an DMUX filters and then detected by 43Gbps receiver for each modulation.



Fiber Type	DMF
Span Length	70 km
Span Averaged Dispersion	-3.5 ps/nm/km
Block Averaged Dispersion	-0.4 ps/nm/km
Number of Repeaters	96
Repeater Output Power	+15.8 dBm
Noise Figure	4.5 dB

Figure 4: Experimental Setup

3.2 Transmission Performance

In order to evaluate the channel power dependency, pre-emphasis technique is utilized by adjusting the power level between modulated signals and CW light sources at the transmitter. In this measurement, we identify the channel power with the received OSNR.

Figure 5 shows the received OSNR and the measured Q values at 6570km for 100GHz spaced RZ-DPSK and 50GHz spaced RZ-DQPSK for each channel power setting. For 100GHz spaced RZ-DPSK signals, optimal channel power is around -2dBm/ch and maximum Q value is 11.1dB. For 50GHz spaced RZ-DQPSK signals, optimal channel power is around -3dBm/ch and maximum Q value is 10.5dB.

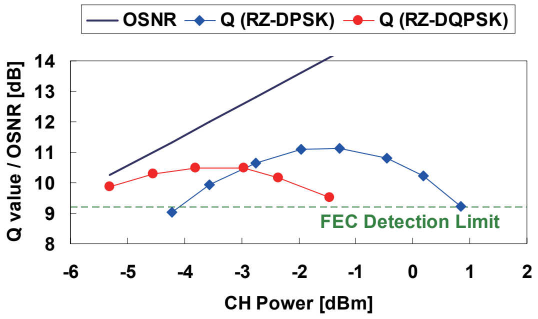
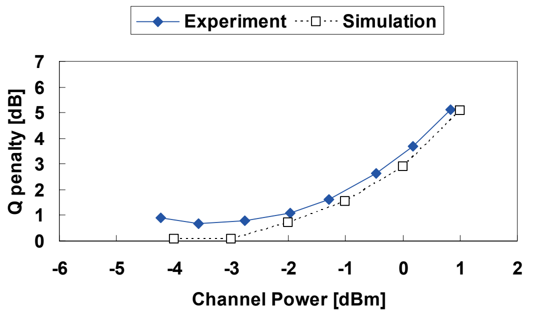


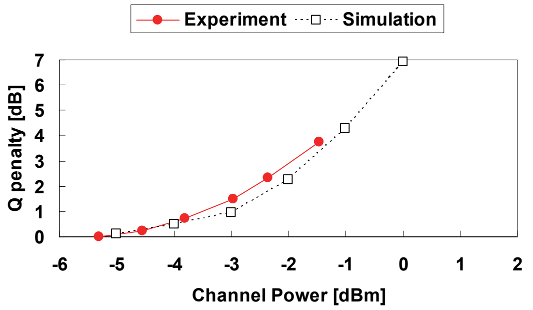
Figure 5: Channel Power vs Q value at 6570km

Figure 6 shows the comparison of resulting Q penalty for experimental and simulation for each modulation format. Q penalty is defined as the difference between the measured Q value and the estimated Q value from received OSNR.

From this figure, experimental Q penalties for both 100GHz spaced RZ-DPSK and 50GHz spaced RZ-DQPSK signals are in excellent agreement with the simulations, which indicates that we can estimate the comprehensive system performance with reasonable accuracy by using well-calibrated simulation.



(a) 100GHz spaced RZ-DPSK



(b) 50GHz spaced RZ-DQPSK

Figure 6: Q Penalty at 6570km for Experiment and Simulation

4. ADVANCED MODULATION FORMAT TOWARD TRANS-PACIFIC REACH

Based on the above evaluation, 100GHz spaced RZ-DPSK signal shows superior nonlinear tolerance compared to 50GHz RZ-DQPSK signal. However, 100GHz spaced 40Gbps RZ-DPSK signal can not expect higher capacity compared to the 25GHz spaced 10Gbps systems. In order to achieve higher capacity, 40Gbps WDM systems with channel spacing of 50GHz or less is indispensable.

Among some of the popular 40Gbps phase modulation-based technologies, the polarization multiplexed, digital coherent communication systems have been shown to be advantageous in many aspects, such as high receiver sensitivity and high tolerance to fiber chromatic dispersion (CD), polarization mode dispersion (PMD) and linear channel filterings.

Toward the trans-Pacific reach beyond the distance limitation of 50GHz spaced RZ-DQPSK system, we numerically evaluate three types of 40Gbps modulation format using digital coherent technologies, Dual-

Polarization Return-to-Zero Quadrature Phase Shift Keying (DP-RZ-QPSK), DP-RZ Binary Phase Shift Keying (DP-RZ-BPSK) and Single-Polarization RZ-QPSK (SP-RZ-QPSK).

Figure 7 shows the channel power dependency of 50GHz spaced 43Gbps signals at 6500km for each modulation format. Simulated span length is set to 60km. Transmission line configuration and dispersion map are the same as the previous RZ-DQPSK simulation. Although DP-RZ-QPSK signals shows the poor non-linear tolerance, performance improvement of around 0.5dB is confirmed than RZ-DQPSK signals, thanks to its superior receiver sensitivity. According to this simulation, DP-RZ-BPSK and SP-RZ-QPSK show more than 1.5dB better performance compared to RZ-DQPSK.
Beyond 6500km transmission of 50GHz spaced 40Gbps systems, DP-RZ-BPSK and SP-RZ-QPSK, which have not only high sensitivity, but also comparable nonlinear tolerance as RZ-DQPSK, seem to be promising modulation candidates.

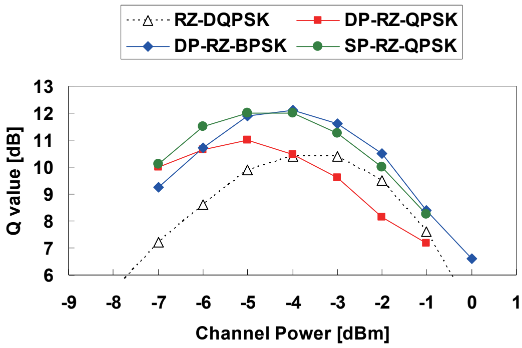


Figure 7: Numerical Q value Estimation for DSP Assisted Coherent 40Gbps Systems

5. CONCLUSION

Our study results of 40Gbps system optimization for RZ-DPSK and RZ-DQPSK signals have been presented. Maximum transmissible reaches of 6500km with RZ-DPSK and 5000km with RZ-DQPSK are confirmed numerically and experimentally. For further expansion of the transmission distance of 40Gbps DWDM systems, digital coherent systems are also simulated and confirmed that 1.5dB improvement by applying DP-RZ-BPSK and SP-RZ-QPSK signals.

6. REFERENCES

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