# 100G TRANS-PACIFIC TRANSMISSION WITH EXTREMELY HIGH SPECTRAL EFFICIENCY

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**Abstract:** This paper describes our study results for deploying 100 Gb/s trans-Pacific distance transmission. We show feasibility of DP-QPSK modulation format with optical spectral shaping enabling to improve non-linear tolerance and spectral efficiency. We also introduce higher multi-level modulation formats in terms of their transmission performance and achievable extremely high spectral efficiency of 4.7 bit/s/Hz.

## 1 INTRODUCTION

In accordance with the growth of internet traffic, the capacity of submarine cable systems has increased dramatically in recent years. Higher bit rate signals are able to be transmitted over trans-Pacific distances by a combination of multiple level modulation formats, polarization multiplexing, coherent detection, digital signal processing and uncompensated fibre links. Especially, 100 Gb/s systems for trans-Pacific transmission are scheduled to be commercialized in the immediate future.

Aiming towards the trans-Pacific distance transmission of 100 Gb/s-based WDM signals, we have investigated technologies such as digital coherent DP-QPSK modulation, powerful Forward Error Correction (FEC), and ultra-low loss / low nonlinearity fibres in optimized line designs. We have confirmed by experiment that over 10,000 km transmission of 100 Gb/s DP-QPSK signal with 50 GHz channel spacing is feasible, while maintaining adequate system operation margins.

For further capacity enhancement, we have also studied two approaches for narrowing 100 Gb/s channel spacing. One is to apply optical pre-spectral shaping. We have confirmed its effectiveness for mitigating the linear and non-linear cross-talk of 100 Gb/s signals with 37.5 GHz spacing through long-haul transmission simulations. The other is to use higher multi-level modulation formats. We have investigated DP-8QAM and DP-16QAM modulation formats in terms of their transmission performance and achievable spectral efficiency. Through these assessments, we have experimentally confirmed the feasibility of 100 Gb/s DP-16QAM signal transmission over 10,000 km with an extremely high spectral efficiency of 4.7 bit/s/Hz.

## 2 100GB/S DP-QPSK TRANS-PACIFIC DISTANCE TRANSMISSION SYSTEM

DP-QPSK is one of the most attractive modulation formats for 100 Gb/s trans-Pacific distance transmission. Reduction of system baud rate by combination of polarization division multiplexing / quadrature phase shift keying and a coherent detection technology contribute to improve receiver sensitivity of 100 Gb/s signals, and a digital signal processing (DSP) technology enables compensation of waveform distortion caused by chromatic dispersion (CD) and polarization mode dispersion (PMD).

## 2.1 Feasibility of DP-QPSK Trance-Pacific Distance Transmission

We have evaluated a transmission performance of 100 Gb/s DP-QPSK signals over 10,000 km distance experimentally. Figure 1 shows an experimental setup. Optical signals from the sets of odd and even external cavity lasers (ECL) were individually modulated by 100 Gb/s DP-QPSK modulators and interleaved by an inter-leaver to form 50 GHz channel spacing. DP-QPSK signals are combined with continuous wave (CW) dummy lights ranged from 1530.73 nm to 1565.50 nm and injected to a re-circulating loop transmission line which consists of seven single mode fibre (SMF) spans, nine EDFAs, a gain equalizer (GEQ) and a polarization controller (PC). The each fibre span has length of 60 km and the average span loss was 10.6dB including connection loss between fibre and EDFA. The average dispersion and dispersion slope of the transmission line at 1550 nm were +20.5 ps/nm/km and 0.0614 ps/nm$^2$/km, respectively. We set the output power of the EDFAs to +16.5 dBm, resulting channel power is -2.9 dBm/ch as nominal condition. In the receiver side, the transmitted signal to be measured was selected by a 50 GHz de-multiplexer (DEMUX) and detected by a coherent receiver. Digitized signals from an analog / digital convertor (ADC) were operated by an off-line DSP which compensated waveform distortions, and calculated a bit error rate (BER). Figure 2 shows an optical spectrum of 50 GHz spaced 88 WDM signals after 10,080 km distance transmission (24 loops) for an example.

Figure 3 shows transmission distance dependency at 1547.72 nm. 50 GHz spaced 100 Gb/s DP-QPSK signal with spectral efficiency of 2.0 bit/s/Hz achieved transmission performance with 3 dB margin over FEC limit [1] after 10,000 km distance.

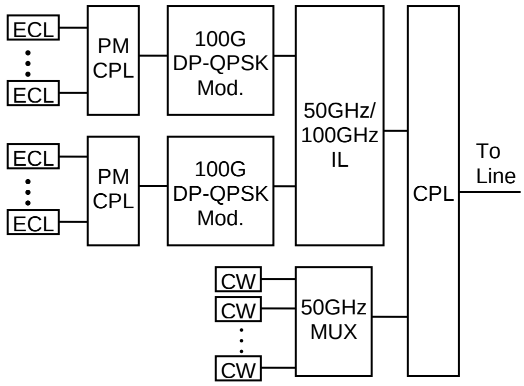


**Figure** 1(a) **: Transmitter Side**

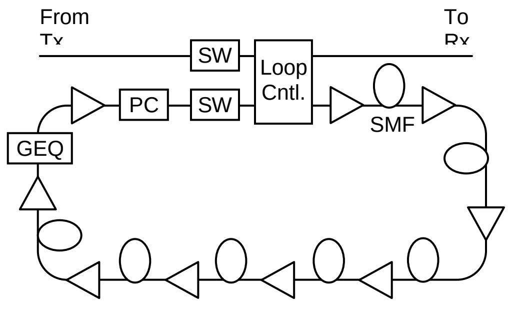


**Figure** 1(b) **: Re-circulating Loop**

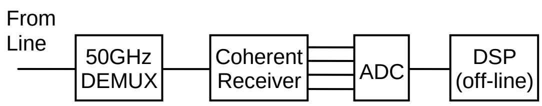


**Figure** 1(c) **: Receiver Side**

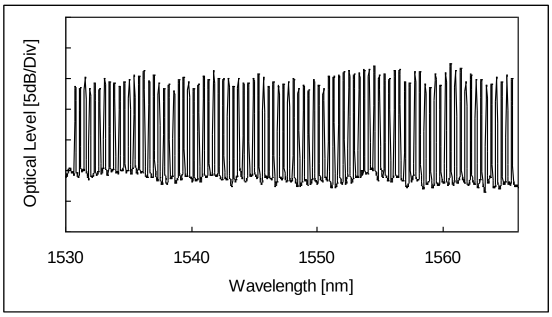


**Figure 2: Optical Spectrum after 10,080 km Transmission**

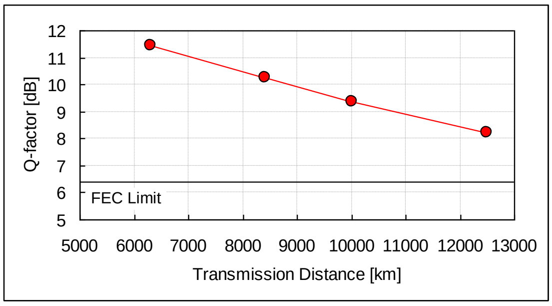


**Figure 3 : Transmission Distance Dependency with 50 GHz Channel Spacing**

## 2.2 DP-QPSK with Narrower Channel Spacing

Adaptation of narrower channel spacing is one of the methods to increase the transmission capacity. However, narrow channel spacing induces linear and non-linear cross-talk between neighbouring channels as shown in Figure 4. From this figure, the linear penalty of 40 GHz and 37.5 GHz channel spacing is 0.2 dB and 0.8 dB, respectively. Moreover, the penalties increase due to the non-linear cross-talk after 10,000 km transmission. A spectral pre-shaping technique is effective to reduce the penalties caused by narrower channel spacing, because a Nyquist-like spectral shape contributes to mitigate inter-channel interference (Figure 5).

We have evaluated Q-factor as a function of channel power changing the channel spacing from 50 GHz to 31 GHz by a numerical simulation. Figure 6 shows that penalty with wider channel spacing than 38 GHz is negligible small, while penalties with narrower channel spacing than 35 GHz become larger. Considering 37.5 GHz channel spacing which conforms to a flexgrid, 100 Gb/s DP-QPSK signals which are multiplexed with an ideal Niquist spectral shape can achieve the same performance as 50 GHz channel spaced system increasing the spectral efficiency to 2.67 bit/s/Hz.

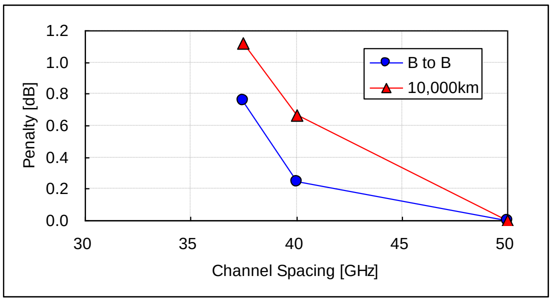


**Figure 4 : Penalty of Narrower Channel Spacing without Spectral Pre-Shaping**

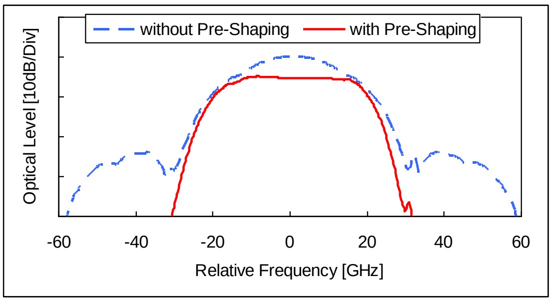


**Figure 5: Optical Spectrum with Spectral Pre-Shaping**

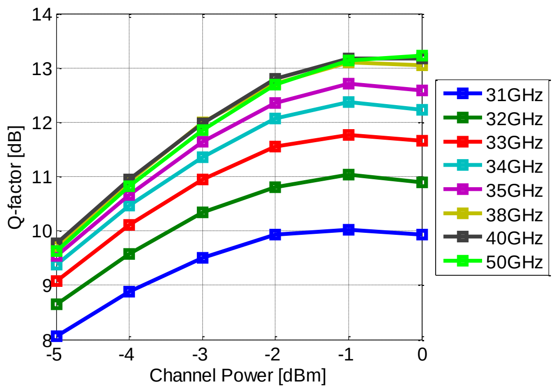


**Figure 6: Comparison of Channel Power Dependency with Pre-Shaping (Simulation)**

## 3 100 GB/S QAM TRANSMISSION

Another method to enhance the spectral efficiency is to deploy a higher multi-level modulation format. 8QAM and 16QAM signals respectively carry 3 bits and 4 bits per a symbol and enable an extremely high spectral efficiency.

We have demonstrated 100 Gb/s DP-8QAM [2] and DP-16QAM [3] transmission over 10,000 km. We generated 115 x 100 Gb/s DP-8QAM signals and 40 x 117.6 Gb/s DP-16QAM signals with 25 GHz channel spacing for each demonstration and the spectral efficiency became 4 bit/s/Hz and 4.7 bit/s/Hz, respectively. A re-circulating transmission line consists of seven 60.6-km fibre span, eight EDFAs and a GEQ. In receiver side, digitized signals were processed by an off-line DSP.

Figure 7 shows transmission distance dependence of 8QAM signal and 16QAM signal. We can achieve Q factor of 7.7 dB with DP-8QAM signal after 10,000 km transmission. This result means that DP-8QAM modulation format is one of the candidates for the trans-Pacific communications. Since distance of each phase becomes closer in 16QAM signals, a non-linear phase tolerance becomes lower. In order to achieve the trans-Pacific distance transmission with 16QAM signal, we have introduced a novel nonlinear compensation (NLC) technique and a powerful FEC. After adapting our digital backpropagaion-based nonlinear compensation (NLC) [4] for 16QAM signals, Q factor improved around 1 dB. We also confirmed that all the received bit errors of coded PRBS data were successfully corrected by using quasi-cyclic low-density parity-check (QC-LDPC) [5].

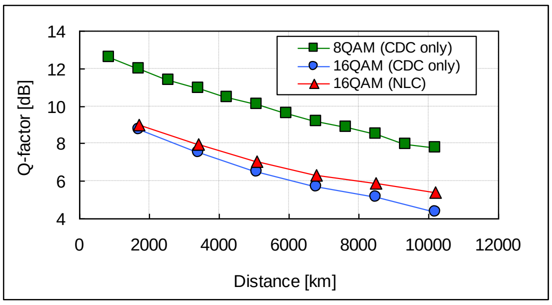


**Figure 7: Transmission Distance Dependence of 8QAM and 16QAM**

## 4 CONCLUSION

We introduced our study results of 100 Gb/s signal transmission with high spectral efficiency. We have showed the feasibility of the pre-shaped DP-QPSK with SE of 2.67 bit/s/Hz, 8QAM and 16QAM with SE of 4 bit/s/Hz and 4.7 bit/s/Hz over trans-Pacific distance.

## 5 REFERENCES

[1] T. Mizuochi et al., “Progress in Soft-Decision FEC” OFC2011, Paper NWC2.

[2] D. Qian et al., “Transmissio of 115x100G PDM-8QAM-OFDM Channels with 4bits/s/Hz Spectral Efficiency Over 10,181km” ECOC 2011, PD Th.13.K.3.

[3] S. Zhang et al., “40x117.6 Gb/s PDM-16QAM OFDM Transmission over 10,181 km with Soft-Decision LDPC Coding and Nonlinearity Compensation” OFC 2012, PDP5C.4.

[4] E.Mateo et al., “Nonlinearity Compensation using Very-Low Complexity Backward Propagation in Dispersion Managed Links” OFC 2012, Paper Oth3C.4.

[5] I. B. Djordjevic et al., “Next Generation FEC for High-Capacity Communication in Optical Transport Networks” JLT. 27 (16), pp 3518, 2009.

 