RZ-DQPSK TRANSPONDER FOR 40 GBPS SUBMARINE CABLE SYSTEMS

Kazuyuki Ishida, Katsuhiro Shimizu, Shunsuke Mitani, Junichi Abe, Toshiyuki Tokura,Takashi Mizuochi

Ishida.Kazuyuki@dy.MitsubishiElectric.co.jp

Mitsubishi Electric Corp., 5-1-1, Ofuna, Kamakura, Kanagawa, 247-8501, Japan.

Abstract: 40 Gbit/s per wavelength operation is approaching commercialization for upcoming submarine systems. However one major concern in 40 Gbps transmission has not been resolved yet: the effects of cumulative polarization mode dispersion (PMD) in a long fiber cable. For reducing the performance degradation due to PMD, return-to-zero differential quadrature phase-shift keying (RZ-DQPSK) holds promise because of its broad pulse width. We have developed an RZ-DQPSK transponder and confirmed experimentally its large DGD tolerance and highly stable performance. We believe that this RZ-DQPSK transponder opens up the possibility of building next generation 40Gbps submarine cable systems.

1 INTRODUCTION

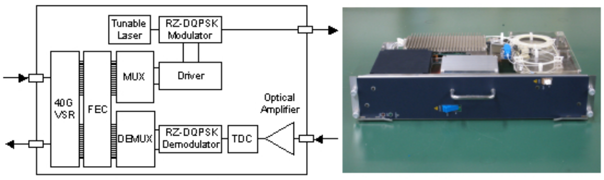
40 Gbps DWDM has been seen as a promising candidate for next generation submarine systems for some years because it reduces the number of wavelengths, resulting in easier operation and maintenance. It can also potentially reduce the footprint of the Line Terminal Equipment (LTE) by a quarter. However, a challenge in higher bit-rate transport systems is to improve the tolerance to unwanted waveform distortions due to wavelength chromatic dispersion, polarization mode dispersion (PMD) and nonlinear effects. Among these, PMD is a critical factor in limiting transmission distance. Recent studies have shown that large PMDs can be found in installed fibers in a small but non-negligible percentage of cases [1]. In submarine cable systems, although it may be possible to employ lower PMD fiber, the total PMD across transoceanic distances would still be large. Although electrical or optical PMD compensators have been also investigated, good PMD tolerance remains essential for optical transmission systems because of the inherently statistical behavior of PMD.

One way to improve PMD tolerance is by employing a multilevel modulation format such as Differential Quadrature Phase Shift Keying (DQPSK), which is also of major interest for next generation optical network systems for its expected improvement in receiver sensitivity over conventional on-off keying (OOK) [2]. As a DQPSK signal has half the symbol rate of OOK, its PMD tolerance is twice that of either OOK or DPSK. In addition, a DQPSK signal has potentially larger chromatic dispersion tolerance and higher spectrum efficiency than OOK [3-5]. For these reasons, most of the 40 Gbps transmission experiments reported recently have employed DQPSK [6-8].

One remaining practical question is whether it is possible to obtain the expected performance from the relatively complex DQPSK transponders. In order to verify the practicability of DQPSK transponders, we investigate a 40 Gbps RZ-DQPSK transponder developed for submarine line terminals. The transponder consists of an OC768 VSR (Very Short Reach) module, an enhanced FEC (Forward Error Correction) based OTN (Optical Transport Network) framer, an RZ-DQPSK modulator and demodulator, a tunable dispersion compensator [9], a tunable laser and a control processor. We demonstrate the superior performance and reasonable stability of the transponder.

2 40 GBPS RZ-DQPSK TRANSPONDER

Figure 1 (a) shows the functional block diagram of the 40 Gbps RZ-DQPSK transponder we have developed. It consists of an OC768 VSR module, an enhanced FEC based OTN framer, a MUX / DEMUX, a tunable laser that covers over 35 nm at ITU-T 100 GHz grid spacing, an RZ-DQPSK modulator and demodulator, a modulator driver, a fiber grating based tunable dispersion compensator, an optical amplifier and a control processor. The OC768 VSR module, which we have recently developed, is a fully ITU-T compatible 300-pin module, operating at 40 or 43 Gbps with an MSA-compatible small package size (4 x 5 inches). Its receiver sensitivity is higher than -8 dBm after 2 km transmission. The RZ-DQPSK modulator is fully stabilized by a lock-in control circuit using superimposed low frequency dithering. The tunable dispersion compensator used covers either the odd or even channels of the ITU-T 100 GHz grid spacing over 40 nm. Its dispersion tuning range is more than +/- 400 ps/nm over all channels. Two pairs of 1 bit delay demodulators and twin photo-diodes are integrated to form the RZ DQPSK demodulator, and the demodulator is fully stabilized by an automatic control circuit. Figure 1 (b) shows the appearance of the transponder.



(a) Functional block diagram (b) Outline of transponder

Figure 1: 40 Gbps RZ DQPSK transponder.

3 PERFORMANCE OF 40 GBPS RZ-DQPSK TRANSPONDER

In order to verify the performance of the 40 Gbps RZ-DQPSK transponder, we measured the Q-tolerance to optical noise, GVD (Group Velocity Dispersion) and DGD (Differential Group Delay). We also compared this with the corresponding performance of a RZ-DPSK transponder to clarify the pros and cons of the DQPSK format. A PRBS 31 test pattern was used for the measurement. To evaluate the dispersion tolerance of the transponder itself, the tunable dispersion compensator (TDC) was set at a fixed value. The received optical SNR was adjusted by an ASE noise loading system.

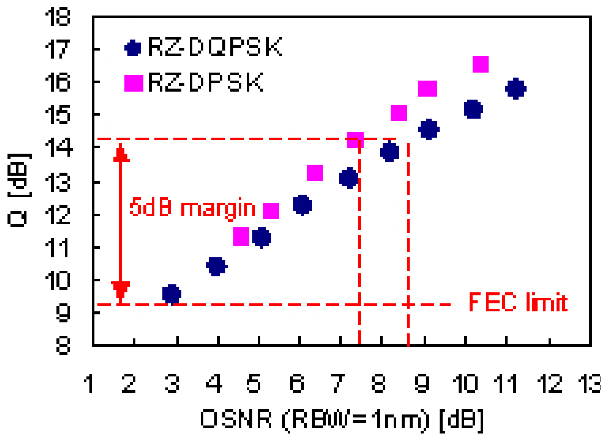
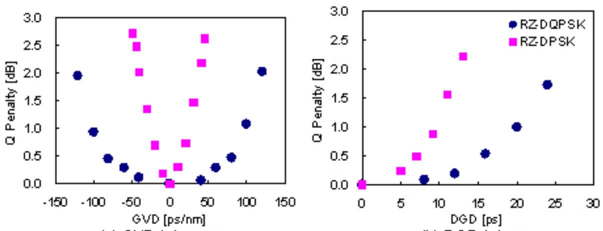


Figure 2: Measured Q vs. OSNR of 40 Gbps RZ-DQPSK transponder

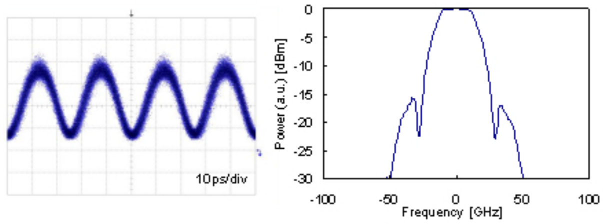
Figure 2 shows the back-to-back Q performance of the transponder as a function of the received optical SNR. The circles and squares show respectively the measured data for RZ-DQPSK and RZ-DPSK. The optical SNR required to obtain a Q factor of 14.1 dB, which is 5 dB better than the FEC limit, was 8.5 dB (1 nm resolution bandwidth) and is comparable to that for RZ-DPSK.



(a) GVD tolerance (b) DGD tolerance

Figure 3: Tolerance of 40 Gbps RZ DQPSK transponder to GVD and DGD

Figure 3 shows the tolerance to GVD and DGD at a received optical SNR of 10 dB (corresponding to a Q of 15.0 dB). At 1dB penalty, the GVD tolerance was +/-100 ps/nm and the DGD tolerance measured was 20 ps. The GVD tolerance of DQPSK is twice of that of DPSK, and the DGD tolerance is four times of that of DPSK, which are consistent with the predicted values. Thanks to its wider pulse width, RZ-DQPSK showed a large tolerance even without a TDC, although a TDC will be helpful for ease of system installation. The rate of system outage based on the DGD tolerance is discussed in the next section. The transmitted optical waveform and the optical spectrum of the RZ-DQPSK signal are shown in Fig. 4.



(a) Optical waveform (b) Optical spectrum

Figure 4: Transmit optical waveform and spectrum of 40 Gbps RZ DQPSK transponder.

Figure 5 shows the long-term back-to-back Q performance of the RZ-DQPSK transponder measured continuously over 12 hours, sampled every 1 second, at the received OSNR of 7 dB. The Q variation was successfully held to within 0.4 dB.

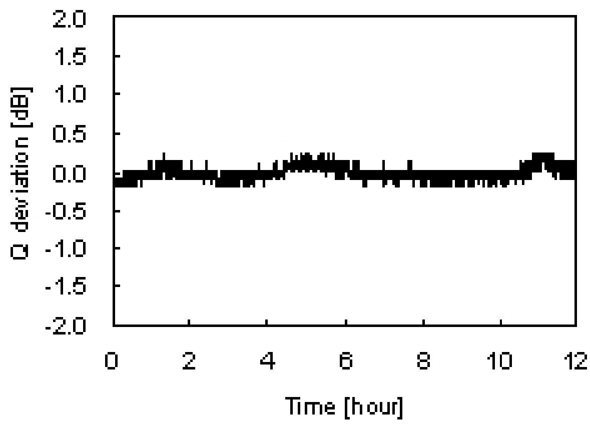


Figure 5: Results of long-term BER measurement.

We see that the 40 Gbps RZ-DQPSK transponder has matured sufficiently to show reasonable tolerance to SNR, GVD and DGD, and to exhibit long term stability.

4 DISCUSSION

In this section, we discuss system outages due to unwanted PMD in long haul systems. Assuming that the fiber PMD is 0.11 ps/km$^{1/2}$ including the optical repeaters, and that the total fiber length is 4,000 km, the mean DGD (PMD) is calculated to be 7 ps. Figure 6 (a) shows the probability density at a mean DGD of 7 ps;

where the full line shows the probability density and the dotted line shows the probability. Figure 6 (b) shows the calculated system outage rate due to PMD.

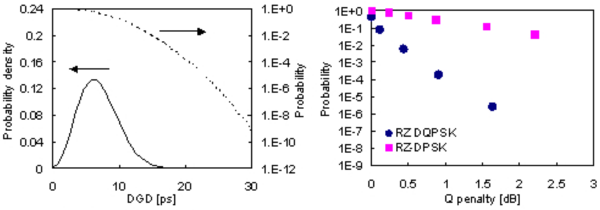


Figure 6: Estimated system outage probability due to PMD.

The horizontal axis is the Q penalty due to DGD, and the vertical axis is the probability of exceeding the Q penalty. The circles show the Q penalty probability for RZ-DQPSK and the squares show that for RZ-DPSK. In the case of RZ-DQPSK, the DGD penalty exceeds 2 dB when the DGD is larger than 25 ps, which can occur with a probability of 10^{-7} in a transmission line having a mean DGD of 7 ps. In the case of RZ-DPSK, the probability is far greater at 10^{-1} under the same condition. From the point of view of system outages, an RZ-DQPSK transponder exhibits a large improvement compared to an RZ-DPSK transponder at 40 Gbps.

5 CONCLUSIONS

We have developed a 40 Gbps RZ-DQPSK transponder for submarine line terminals. Transmission experiments showed superior performance and stability. A GVD tolerance of +/- 100 ps/nm was confirmed even without active dispersion compensation: the additional tolerance of +/- 400 ps/nm obtained with TDC will facilitate the installation of 40 Gbps systems. Error free operation was achieved even with a received OSNR of only 8.5 dB, with a 5 dB FEC margin. The Q variation over 12 hours was held to within 0.3 dB. The measured DGD tolerance of 25 ps at 2dB penalty results in an estimated system outage due to a PMD of 7 ps of only 10^{-7}. These superior performance characteristics demonstrate the technical maturity of 40 Gbps systems for submarine cables.

6 REFERENCES

[1] M. Karlsson, J. Brentel, and P. A. Andrekson, “Long-term measurement of PMD and polarization drift in installed fibers,” IEEE J. Lightwave Technol., vol. 18, no. 7, pp. 941-951, July 2000.

[2] R. A. Griffin and A. C. Carter, “Optical differential quadrature phase-shift key (oDQPSK) for high capacity optical transmission,” Technical Digest of OFC 2002, paper WX6, Anaheim, March 2002.

[3] P. S. Cho, V. S. Grigoryan, Y. A. Godin, A. Salamon, and Y. Achiam, “Transmission of 25-Gb/s RZ-DQPSK Signals With 25-GHz Channel Spacing Over 1000 km of SMF-28 Fiber,” Photon. Technol. Lett., vol. 15, no. 3, pp. 473 –475, March 2003.

[4] H. Kim and R.-J. Essiambre, “Transmission of 8 x 20 Gb/s DQPSK Signals Over 310-km SMF With 0.8-b/s/Hz Spectral Efficiency,” Photon. Technol. Lett., vol. 15, no. 5, pp. 769 –771, May 2003.

[5] K. Ishida, K. Shimizu, T. Mizouchi, K. Motoshima, D.-S. Ly-Gagnon, and K. Kikuchi “Transmission of 20 x 20 Gb/s RZ-DQPSK signals 5090 km with 0.53 b/s/Hz spectral efficiency,” Technical Digest of OFC2004, paper FM2, Los Angels, Feb. 2004.

[6] A. H. Gnauck, P. J. Winzer, S. Chandrasekhar, and C. Dorrer, “Spectrally efficient (0.8 b/s/Hz) 1-Tb/s (25 × 42.7 Gb/s) RZ-DQPSK transmission over 28 100-km SSMF spans with 7 optical add/drops,” Proceeding of ECOC 2004, paper Th4.4.12, Stockholm, Sep. 2004.

[7] G. Charlet, P. Tran, H, Mardoyan, M. Lefrancois, T. Fauconnier, F. Jorge, and S. Bigo, “151 × 43 Gb/s transmission over 4,080 km based on Return-to-Zero-Differential Quadrature Phase-Shift Keying,” Proceeding of ECOC 2005, paper PDP4.1.3, Glasgow, Sep. 2005.

[8] J.-X. Cai, M. Nissov, C. R. Davidson, W. Anderson, Y. Cai, A. N. Pilipetskii, D. G. Foursa, W. W. Patterson, P. C. Corbett, A. J. Lucero, and N. S. Bergano, “Improved margin in long-haul 40 Gb/s systems using bit-synchronously modulated RZ-DQPSK,” Technical Digest of OFC/NFOEC2006, paper PDP33, Anaheim, March 2006.

[9] S. Matsumoto, T.Ohira, M.Takabayashi, K.Yoshiara, and T Sugihara, “Tunable dispersion Equalizer with a divided Thin Film heater for 40Gb/s RZ transmission,” IEEE Photon. Technol. Lett., vol.13, No. 8, pp. 827-829, Aug. 2001.