

RZ-DPSK Field Trial over 13,100 km of Installed Non Slope-Matched Submarine Fibers

J.-X. Cai, D. G. Foursa, L. Liu, C. R. Davidson, Y. Cai, W. W. Patterson, A. J. Lucero, B. Bakhshi, G. Mohs, P. C. Corbett, V. Gupta, W. Anderson, M. Vaa, G. Domagala, M. Mazurczyk, H. Li,

M. Nissov, A. N. Pilipetskii, and Neal S. Bergano

Tyco Telecommunications, 250 Industrial Way West, Eatontown NJ 07724, USA
732 578 7585 (voice) 732 578 7302 (fax), jcai@tycotelecom.com (email)

Abstract: We successfully conducted a 96x10Gb/s RZ-DPSK field trial over an installed 13,100km optical undersea path with more than 3dB FEC margin, including channels with >13,000ps/nm dispersion. The performance was further improved 1-2dB by adding pre-chirp.

©2004 Optical Society of America

OCIS codes: (060.2330) Fiber optics communications; (060.4080) Modulation; (060.5060) Phase modulation

1. Introduction

The RZ-DPSK modulation format [1-2] is a promising candidate for next generation optical communication systems, offering a potential 3 dB reduction in required received OSNR for a particular BER. This margin improvement has been demonstrated in both 40 Gb/s [1, 3, 4] and 10 Gb/s [5-7] laboratory transmission experiments using slope-matched fiber sets. However, it is not obvious that this advantage is also present in long-haul systems using the conventional non slope-matched dispersion shifted fibers, especially when the accumulated dispersion is very large (e.g. >5,000 ps/nm). Furthermore, there has been no field trial to confirm the DPSK benefit yet.

In this paper, we report the first field trial using the RZ-DPSK modulation format. We present the successful transmission of ninety-six 10 Gb/s RZ-DPSK channels (33 GHz channel spacing) over 13,100 km of non slope-matched fibers, in the Atlantic section of the Tyco Global Network™ (TGN-A). All channels performed better than 11 dB, with more than 3 dB margin over the FEC threshold (FEC margin) even though the accumulated dispersion varied over a range of $\pm 13,000$ ps/nm across the signal bandwidth. In addition, we show that the chirped RZ-DPSK format (i.e., RZ-DPSK with bit-synchronous sinusoidal phase modulation) further improved the transmission performance by 1-2 dB for a system operating with a larger channel spacing of 100 GHz.

2. Configuration

One fiber pair on the northern segment of TGN-A was used for the field trial. The undersea cable path is 6,550 km long and connects Wall, NJ in the USA to Highbridge, in the UK (Fig 1a). The deployed fibers are conventional non slope-matched dispersion shifted fibers [8] with a system dispersion slope of ~ 0.08 ps/nm²/km. The 13,100 km path used two passes through the 6,550 km cable (i.e., from the US to the UK and back). The system zero dispersion wavelength is located in the middle of the signal band (~ 1550 nm) and the total accumulated dispersion for the edge channels was $\pm 13,000$ ps/nm (Fig. 1b).

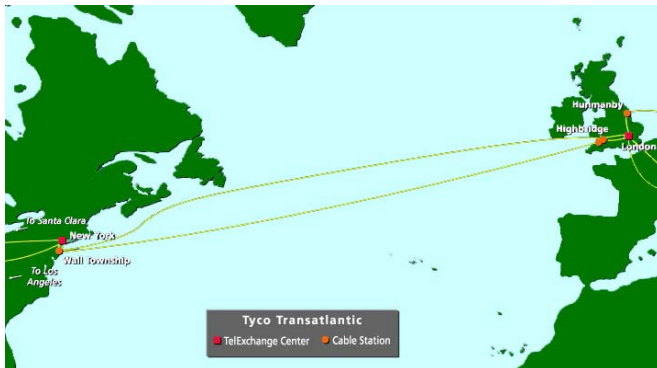


Figure 1a: The Atlantic portion of Tyco Global Network™ (TGN-A) showing both the North and South cables.

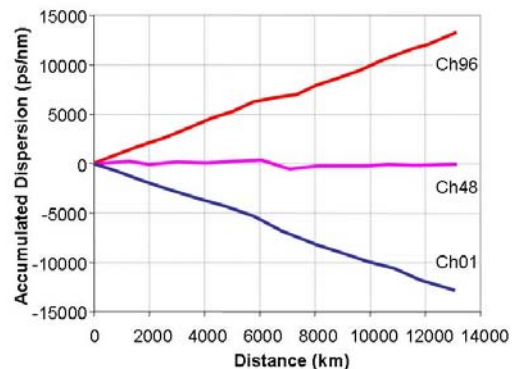


Figure 1b: Accumulated dispersion for selected channels (varied from $-13,000$ to $13,000$ ps/nm)

The RZ-DPSK transmitter and receiver block diagrams are shown in Fig. 2. Ninety-six 33-GHz spaced channels were RZ-DPSK modulated using two modulation paths. The transmitted data was a $2^{23}-1$ PRBS pattern (positive for

the even channels, delayed and inverted for the odd channels) and the transmitted bit rate was 12.3 Gb/s, to account for the FEC overhead. No DPSK pre-coding was required due to the nature of PRBS patterns. The WDM signals were dispersion pre-compensated, and then sent to the undersea line. In the UK, the signals were simply amplified and looped-back to the USA; thus, no dispersion compensation, or any other signal processing was used at the loop-back point. In the receiver, after dispersion post-compensation and optical filtering, the measured channel was demodulated using a 12.3 Gb/s DPSK demodulator and the two optical outputs were sent to a balanced receiver, and finally to an error detector. The error rates of all 96 channels were measured for several minutes each. Due to the large FEC margin (>3 dB), FEC decoding was not necessary and therefore not performed. To ensure the accuracy of our measurements, automatic mechanical polarization controllers were used in auto-scan mode at slow rates to average the performance of each channel over all launched polarization states [9].

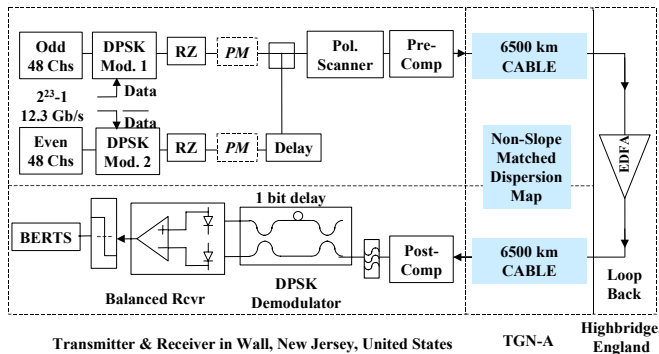


Figure 2: Measurement configuration using (C)RZ-DPSK modulation format and TGN-A

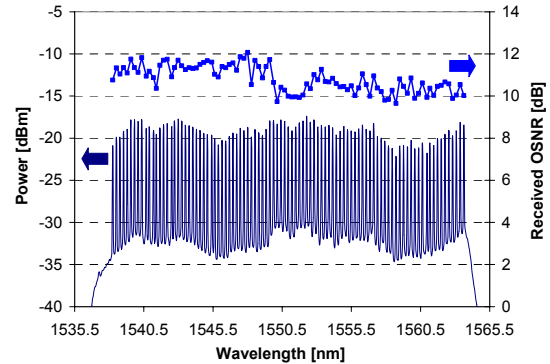


Figure 3: Received optical spectrum and OSNR after 13,100 km (measured with CW tones, in 0.1 nm RBW)

3. Transmission results

Figure 3 shows the received optical spectrum and OSNR after 13,100 km. The optical spectrum was measured with CW tones to resolve the noise floor. The received OSNRs were equalized to within 2 dB by pre-emphasizing the channels at the transmitter end. The average received OSNR in 0.1 nm resolution bandwidth (RBW) was 10.8 dB.

The performance of all 96 channels was measured with the RZ-DPSK modulation format and with optimized pre- and post- dispersion compensation (Fig. 4a). The average Q-factor of all channels was 12.1 dB, and the worst Q-factor was 11 dB. Also shown in the figure are the FEC thresholds for a standard concatenated Reed-Solomon (RS) code with two iterations (8 dB threshold) as well as a soft decision turbo product code (6.3 dB threshold) [10]. Compared to the RS FEC the worst channel had more than 3 dB margin. Using the more advanced FEC would further increase this margin to 4.7 dB.

Figure 4b shows received eye diagrams for two typical channels (Ch 19 and Ch 88). The eye diagrams shown are from left to right: RZ-DPSK before demodulation, output from the demodulator's constructive and destructive ports. Besides the eye closure due to accumulated noise, there is no indication of eye distortion after 13,100 km of transmission.

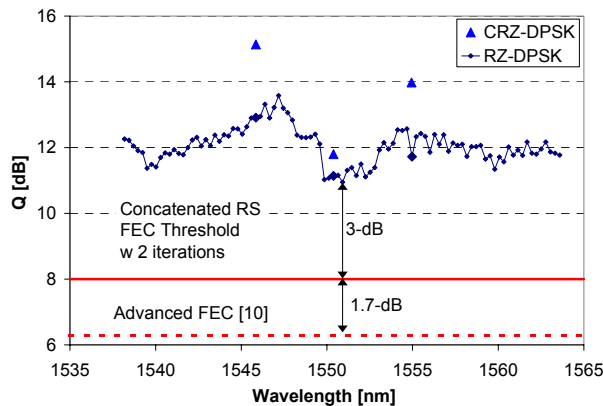


Figure 4a: Q-factor for RZ-DPSK (all 96 channels) and CRZ-DPSK (three selected channels with 100 GHz spacing)

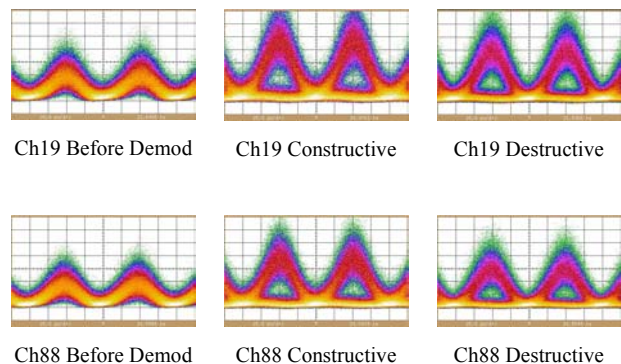


Figure 4b: Eye diagrams for two typical RZ-DPSK channels

4. Advantages of bit-synchronous phase modulation

To explore the possibility of improving channel performance for systems where narrow channel spacing is not required, Chirped RZ-DPSK (or CRZ-DPSK) was studied. The channel spacing of a group of six channels was increased to 100 GHz in order to have enough spectral space for large values of phase modulation. Figure 5a shows the channel performance versus channel power with different levels of phase modulation for channel 30 which had an accumulated dispersion of $-4,700$ ps/nm. The power of the six 100-GHz spaced channels was increased or decreased simultaneously, and channel power is shown relative to the optimum power with 2-radian phase modulation. As phase modulation increased, the channel performance became better and the optimum channel power increased as well. There was 1.8 dB Q-factor improvement for the case with 2-radians of phase modulation compared to the no phase modulation case. Figure 5b shows the performance comparison of balanced and single ended detection. The benefit of balanced detection was the difference between balanced detection and the average of single ended detection using constructive port and destructive port individually. A balanced benefit of ~ 3 dB was seen even at very high channel power. Similar behavior was seen for other values of phase modulation. CRZ-DPSK eye diagrams for Ch30 are shown in the insert of Figure 5b (with 2 radians of phase modulation and optimum channel power). It can be seen that the optical pulse is much narrower compared to the eye diagrams shown in Figure 4b.

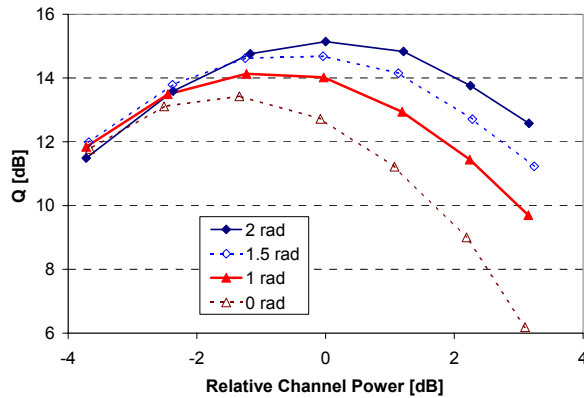


Figure 5a: Q-factor vs channel power for various phase modulation levels (Ch30, 1545.85 nm, 100 GHz channel spacing)

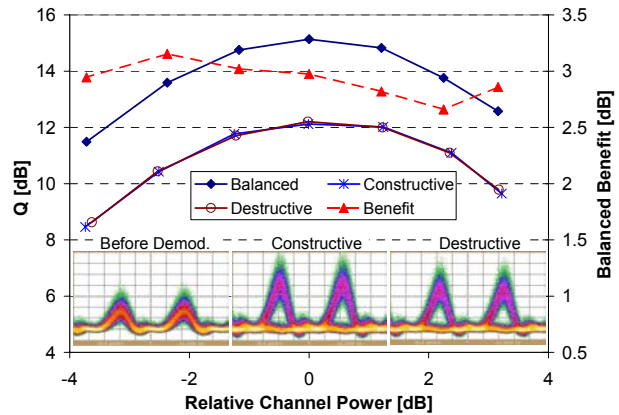


Figure 5b: Comparison of balanced and single ended detection with 2 radians of phase modulation

The effect of synchronous phase modulation was investigated for two more channels, Ch 47 and Ch 64, with -20 , and $+4,600$ ps/nm accumulated dispersion, respectively. Figure 4a also shows the performance of the three channels measured with 2-radian phase modulation and 100 GHz channel spacing. The phase modulation improved the performance by 2.2dB, 0.8dB, 2.3dB for Ch30, 47, 64, respectively. The increased tolerance to high-power could be useful in a system initial deployment where few channels operate at potentially higher than full loading powers.

5. Conclusions

We have conducted the first RZ-DPSK undersea cable field trial. Ninety-six 10 Gb/s RZ-DPSK channels (with 33 GHz channel spacing) were successfully transmitted over 13,100 km of non-slope-matched fibers, in a section of the Tyco Global NetworkTM. Although the accumulated dispersion varied from $-13,000$ ps/nm up to $+13,000$ ps/nm, all channels performed better than 11 dB, with more than 3-dB FEC margin. Furthermore, we showed that the CRZ-DPSK modulation format further improved the system performance by 1-2 dB.

6. References

- [1] A. Gnauck et al., OFC'02, post-deadline paper FC2, Anaheim, CA, Mar 2002
- [2] W. Atia and R. Bondurant, LEOS'99, paper TuM3, p 226, San Francisco, CA 1999
- [3] C. Rasmussen et al., OFC'03, post-deadline paper PD18, Atlanta, GA, March 2003
- [4] I. Morita and N. Edagawa, ECOC'03, post-deadline paper Th4.3.1, Rimini, Italy, Sept. 2003
- [5] J.-X. Cai et al, OFC'03, post-deadline paper PD22, Atlanta, GA, March 2003
- [6] G. Vareille et al., OFC'03, post-deadline paper PD20, Atlanta, GA, March 2003
- [7] L. Becouarn et al., ECOC'03, post-deadline paper Th4.3.2, Rimini, Italy, Sept. 2003
- [8] E. Golovchenko et. al., JSTQE, vol.6, no.2, 2000, pp337-347
- [9] J.-X. Cai et al, OFC'03, paper ThW1, Atlanta, GA, March 2003
- [10] T. Mizuhide et al, OFC'03, post-deadline paper PD21, Atlanta, GA, March 2003