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50 GHz Spaced 4 × 40 Gbit/s WDM Transmission over 700 km Using 6 ps Bandlimited RZ Signals

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Abstract

In this paper, we present 50 GHz spaced 4 × 40 Gbit/s WDM transmission over 700 km using SMF-based Effective Area Enlarged Positive Dispersion Fiber in a recirculating loop. The paper uses bandlimited RZ signals and shows that transmission distance of 700 km can be achieved with BER $\leq 10^{-9}$ using 6 ps pulsewidth for each data signal. To attain this, optical filters with sharp transmission characteristics are used in both transmitter and receiver. The results demonstrated in this paper are based on simulation, and the author believes the propagation distance reached in the paper is the longest distance achieved for such system.

Keywords: Telecommunications, Fiber Optics Communications, Wavelength Division Multiplexing (WDM), Optical Time Division Multiplexing (OTDM), High Speed Optical Transmission

1. Introduction

There has been a big demand to increase the transmission capacities of optical fiber communication systems since these systems were first developed. In fact, increasing the capacities is still under development as telecommunications keep expanding in time. It is well known by telecommunication people that increasing the capacity of optical fiber systems can be either achieved through wavelength division mutliplexing (WDM) or optical time division multiplexing (OTDM) or by a combination of both. OTDM has economic advantage for network operators since the number of terminals is reduced and also because it can accommodate the existing single-band and narrow-band erbium-doped fiber amplifiers (EDFA's), thus no need to spend money on the replacement by broadband amplifiers. Considering this, it would be more practical in many cases to generate 40 Gbit/s signal through OTDM rather than using 4 × 10 Gbit/s WDM signal. Moreover, it is possible to multiply this bandwidth by combining multiple 40 Gbit/s signals through WDM so that the capacity increases significantly. This approach is commonly used in high speed optical transmission systems where a lot of work has already been done like [1], in which nonzero dispersion shifted fiber is used. However, since single mode fiber (SMF) is the basis of most existing fiber optic networks, it has been more realistic to develop and investigate systems using similar fiber in their transmission links. The most worldwide deployed SMF fibers are standard single mode fiber (SSMF) and large effective area fiber (LEAF). Some work has been done on multiple 40 Gbit/s signals using SSMF like [2], which used NRZ modulation format and reached 511 km propagation distance. Another work was presented in [3] showing 4 × 40 Gbit/s WDM transmission over 300 km using RZ format over SSMF. By and large, the LEAF has already shown better results in all modulation formats due to reduced nonlinear effects in the fiber during propagation [4]. Also, RZ signals are more reliable than NRZ and most common in conventional transmission systems using OTDM [5]. Based on that, this paper shall concentrate on transmitting multiple 40 Gbit/s signals over LEAF using bandlimited RZ signals. Similar work was already presented in [6] showing good transmission results over 480 km distance only. Our paper demonstrates successful transmission of 4-channels × 40 Gbit/s WDM signals over 700 km using SMF-based effective area enlarged fiber (or LEAF) with positive dispersion. The four WDM signals are 50 GHz spaced (*i.e.* 0.4 nm), thus the system is considered dense wavelength division multiplexing (DWDM) system. We believe that simulating four DWDM is somehow sufficient to predict the behavior of systems carrying higher number of channels while using less CPU time. In such regime, the investigation would include finding the optimum input power and pulsewidth of the transmitted 4

WDM signals so that the longest possible transmission distance is achieved with acceptable error rate. Indeed, these two parameters play the major role as peak power can cause nonlinearities while pulsewidth can lead to distortion due to polarization mode dispersion (PMD) within the fiber. Actually, the work presented in [6] used 10 ps pulsewidth to reach 480 km transmission distance. However, that work did not show investigation of different pulsewidths thus it is not necessary that 10 ps is the optimal value for the system described. Usually, the pulsewidth used in experiments is limited by the bandwidth of the transmitter's filter available on the test bed. In our work, since we have simulator, it would be possible and easy to examine different pulsewidths in addition to the power to reach the optimum case.

2. Experimental Setup

The experimental setup of our work is shown in **Figure 1**. At transmitter, four laser diodes are used with wavelengths ranging from 1554.4 nm to 1555.6 nm using 50 GHz spacing. The four wavelengths are WDM multiplexed and then modulated by 10 Gbit/s bandlimited RZ data signal to give 4 × 10 Gbit/s signals. The data pattern used is random 128 bits with 50% ones (note: 128 is the data length limit of the simulator). A 4 × 40 Gbit/s bit stream is then generated through two stages co-polarized OTDM, as depicted in **Figure 1**. A fiber link of 1600 km is composed using 40 × 40 km recirculating loop consisting of 2 × 10 km SMF-based effective area enlarged positive dispersion fiber, one 20 km dispersion slope compensating fiber (SCF) and one erbium-doped fiber amplifier (EDFA) repeater. This SMF-SCF configuration allows dispersion flattening over the fiber span within the loop with reduced intra-span dispersion excursion [6]. The dispersion, dispersion slope and effective area of the SMF are 20 ps/nm/km, 0.06 ps/km/nm^2 and 110 μm^2, respectively. The dispersion and dispersion slope of the SCF are the same as for the SMF but in the opposite sign and the effective area is 30 μm^2. Each SMF has an average loss of 0.2 dB/km at around 1550 nm while the SCF's loss is 0.24 dB/km, thus the total loss in the loop span is 8.8 dB. The EDFA is set to 8.8 dB gain to compensate for the entire loop loss. The EDFA noise is 1.5 mW. Optical bandpass filters with ideal Gaussian curve of 0.048 THz bandwidth are used at transmitter and receiver for fine filtration of the unwanted components and to allow little guard-bands between the neighboring channels. The received 40 Gbit/s signals are optically time division demultiplexed back into 4 × 10 Gbit/s signals via two DEMUX stages using two clock recovery circuits as seen in the setup diagram.

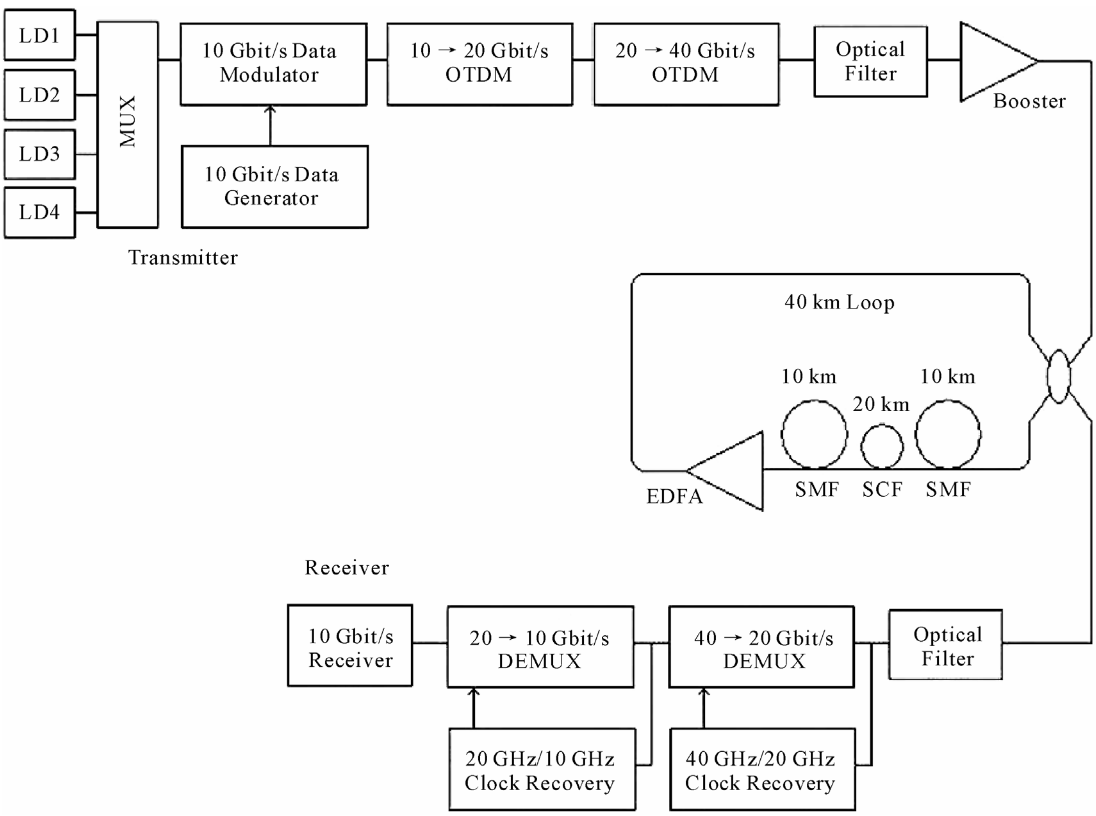

Figure 1. Experimental setup.

For evaluation, the simulator is set such that it produces performance results every 1 km transmission.

3. Results and Analysis

To study the performance of the system described, different peak power and pulsewidth (through full wave half maximum, FWHM) values of the propagating 4×40 Gbit/s signals were examined against transmission distance. Commonly, the performance is evaluated via Q-value or BER where good transmission should exhibit $Q \geq 6$ or BER $\leq 10^{-9}$. Therefore, the optimum distance is effectively the maximum distance that satisfies the above condition. The simulation used peak power values in the range between 1 - 10 mW and FWHM between 5 - 8 ps, where outside these intervals the performance degrades dramatically. This is explained as if the peak power was too small, the system would be impaired by noise where optical signal to noise ratio (OSNR) decreases over short distance. In contrast, if the peak power was too high, the system would be impaired by nonlinearities thus the signal distorts shortly, resulting in high BER. On the other hand, if the pulsewidth was too small, the data signal would loose some of its information and thus errors will be counted upon transmission. If the pulsewidth was too broad, polarization mode dispersion (PMD) would result in inter-symbol interference (ISI) between the neighboring bits thus data will face considerable distortion over short propagation distance. This argument leads us to explore the best values among those in the intervals mentioned above, at which signals are allowed to reach their maximum possible propagation distance. For accuracy, the simulation was run four times for each test and the results were based on average values. This was done as amplifier noise is random thus the results slightly deviate every time the same test is run. **Figure 2** shows the major results obtained from this experiment. It presents the maximum transmission distance obtained with $Q \geq 6$ versus peak power for each 40 Gbit/s signal using different FWHM values.

It is obvious from **Figure 2** that the maximum propagation distance differs from one channel to another, and also differs for different parameters. Apparently, the side signals (Ch. 1 and Ch. 4) often performs better than the

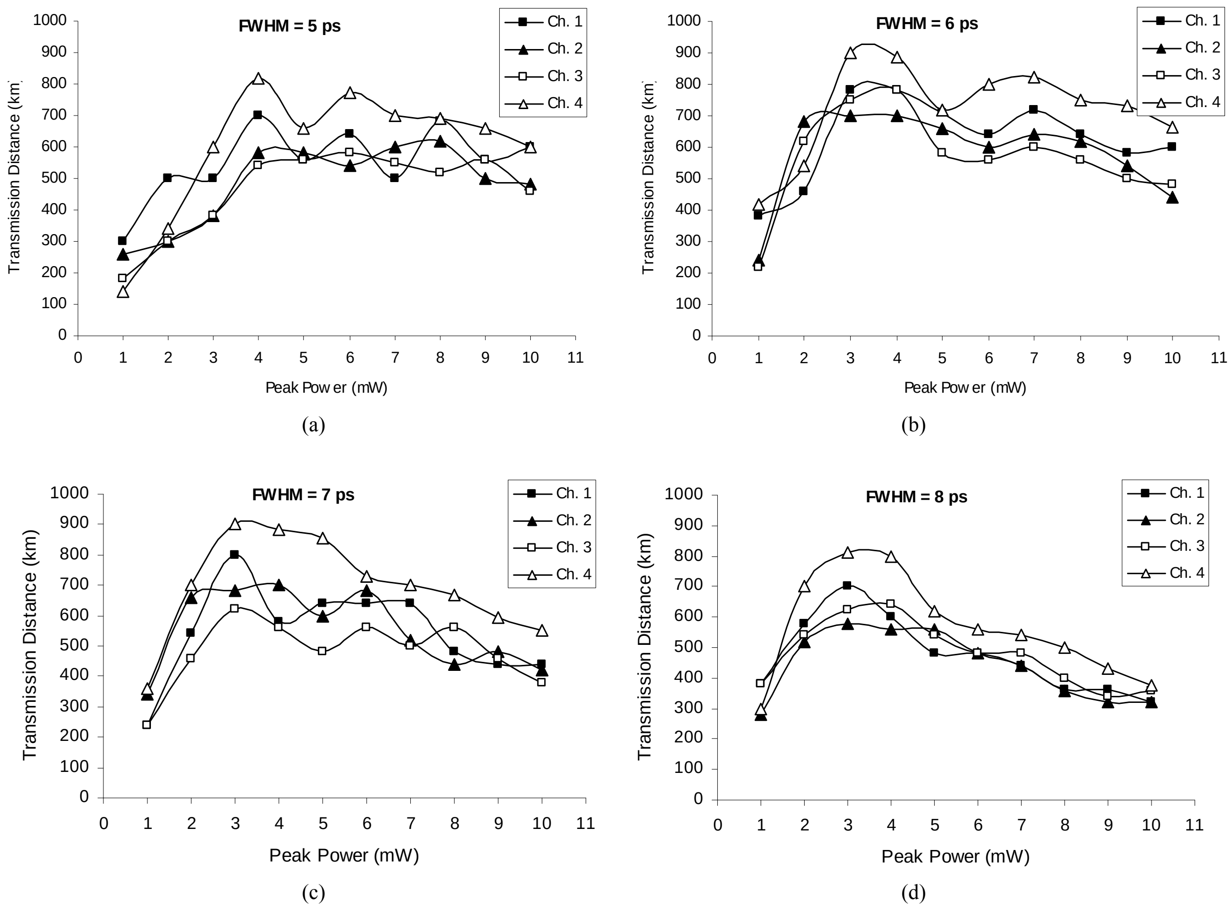

Figure 2. Transmission distance versus peak power for different values of FWHM: (a) 5 ps; (b) 6 ps; (c) 7 ps; and (d) 8 ps. (Channels' definitions: Ch. 1 = 1554.4 nm; Ch. 2 = 1554.8 nm; Ch. 3 = 1555.2 nm; Ch. 4 = 1555.6 nm).

mid channels due to one side interaction thus less inter-channel crosstalk caused by cross phase modulation (XPM) and four wave mixing (FWM). Furthermore, Ch. 4 is still better than Ch. 1 due to better noise characteristics within its band at the transmitter. This can be noticed in **Figure 3** that shows the spectra of the four channels in the transmitter's filter (note that Ch. 4 is the first channel on the right).

To decide on the optimum parameters, the performance of the four signals was compared for different FWHM, and the optimal transmission distance was determined based on a comparison between the worst signals' behaviors. In details, for FWHM = 5 ps shown in (a), good overall performance was achieved for peak power around 4 mW where the maximum distance of the worst signal was 540 km (Ch. 3) although Ch. 4 reached 820 km. Comparing this with other graphs, for FWHM = 6, 7 and 8 ps as in (b), (c) and (d), respectively, good performance was achieved at around 3 mW peak power. This difference in optimum peak power is understood as for 5 ps the signal lost little part of its power thus it needed more power to hit the nonlinear window. However, for 6, 7 and 8 ps pulsewidths, the worst case was: 700 km (Ch. 2), 623 km (Ch. 3) and 580 km (Ch. 2), respectively. As a result of comparing the worst cases, the maximum transmission distance with $Q \geq 6$ achieved for this system can be 700 km and the optimum peak power and pulsewidth are 3 mW and 6 ps, respectively. At these particular values, a good compromise between noise and nonlinear impairments has been attained, and the pulses are broad enough to contain full information and power of the data bits while do not overlap due to PMD effect. Since the transmission results shown in **Figure 2** based on *Q*-value assessment, it would have been necessary to shows *Q*-value versus transmission distance for the given parameters. However, as we are most interested in the optimum parameters, **Figure 4** shows *Q*-value evolution with distance for all channels using 3 mW peak power and 6 ps pulsewidth.

4. Conclusions

In this paper, we demonstrated simulation results for 50 GHz spaced 4 × 40 Gbit/s WDM signals transmission using bandlimited RZ modulation format over SMF-Based Effective Area Enlarged Positive Dispersion Fiber. Transmission performance with BER $\leq 10^{-9}$ was successfully achieved over 700 km using 3 mW peak power and 6 ps pulsewidth for each data signal. The experiment used optical filters with sharp transmission characteristics in both transmitter and receiver.

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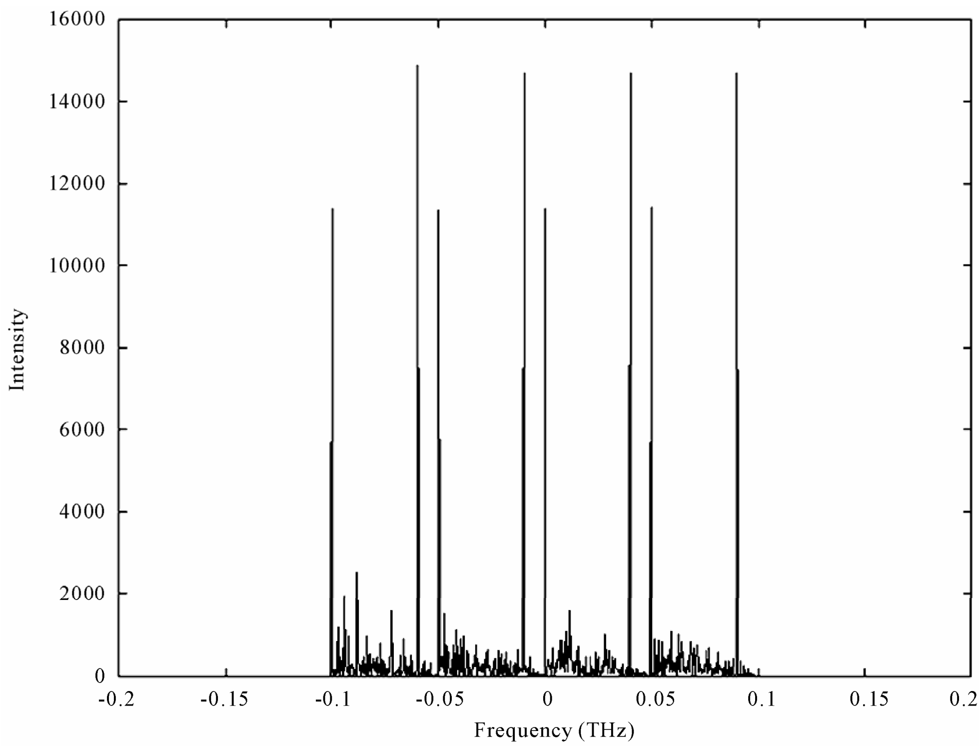

Figure 3. Signals' spectra using Gaussian filter with 48 GHz bandwidth.

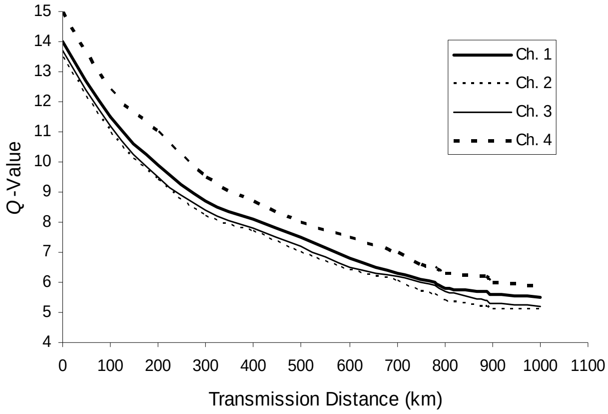

Figure 4. *Q*-value versus propagation distance for all channels using peak power = 3 mW and FWHM = 6 ps. (Channels' definitions: Ch. 1 = 1554.4 nm; Ch. 2 = 1554.8 nm; Ch. 3 = 1555.2 nm; Ch. 4 = 1555.6 nm).

(UK), for providing the author with his self-developed XML-based simulation code.

6. References

[1] J.-X. Cai, C. R. Davidson, M. Nissov, H. F. Li, W. T. Anderson, Y. Cai, L. Li, A. N. Pilipetskii, D. G. Foursa, W. W. Patterson, P. C. Corbett, A. J. Lucero and N. S. Bergano, "Transmission of 40-Gb/s WDM Signals over Transoceanic Distance Using Conventional NZ-DSF with Receiver Dispersion Slope Compensation," *Journal of Lightwave Technology*, Vol. 24, No. 1, 2006, pp. 191-200. doi:10.1109/JLT.2005.861138

[2] S. S. Lee, H.-W. Cho, S.-K. Lim, K.-M. Yoon, Y.-G. Lee, and J. Ko, "Field Trial of 1.6 Tb/s (40 channels × 40 Gb/s) NRZ Signals over 511 km Standard Single Mode Fiber Using Conventional Optical Amplifiers," *IEEE International Conference on Communications* (*IEEE ICC* 2005), Vol. 3, 2005, pp. 1598-1602.

[3] C. M. Weinert, R. Ludwig, W. Pieper, H. G. Weber, D. Breuer, K. Petermann and F. Kuppers, "40 Gb/s and 4 × 40 Gb/s TDM/WDM Standard Fiber Transmission," *Journal of Lightwave Technology*, Vol. 17, No. 11, 1999, p. 2276. doi:10.1109/50.803020

[4] A. Tan and E. Pincemin, "Performance Comparison of Duobinary Formats for 40-Gb/s and Mixed 10/40-Gb/s Long-Haul WDM Transmission on SSMF and LEAF Fibers," *Journal of Lightwave Technology*, Vol. 27, No. 4, 2009, pp. 396-408. doi:10.1109/JLT.2008.929117

[5] R. Ludwig, U. Fieste, E. Dietrich, H. G. Weber, D. Breuer, M. Martin and F. Kuppers, "Experimental Comparison of 40Gbit/s RZ And NRZ Transmission over Standard Singlemode Fiber," *Electronics Letters*, Vol. 35, No. 25, 1999, pp. 2216-2218. doi:10.1049/el:19991504

[6] K. Tanaka, I. Morita and N. Edagawa, "50 GHz Spaced 40 Gbit/s × 25WDM Transmission over 480 km Using Bandlimited RZ Signals," *Electronics Letters*, Vol. 37, 2001, pp. 775-776. doi:10.1049/el:20010540