# OPTIMIZATION OF ALL-OPTICAL NETWORK TESTBED REGARDING NRZ AND RZ MODULATION

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## Abstract

*The non-return-to-zero (NRZ) and return-to-zero (RZ) formats are two well-known cost-effective candidates for the optimum modulation in AON. This paper focuses on the effects of novel active/passive optical devices, such as the photonic switches and erbium doped fibre amplifiers (EDFA), and the effects of modulation formats on the overall system performance, under metro environments without dispersion control/compensation. The overall system performance of an AON metro WDM testbed is investigated by numerical simulation while using NRZ and RZ modulation respectively. Q-factor (equivalent to bit error ratio) is selected as the criterion for the comparison. The testbed is based on commercially available photonic switches, which support dynamic wavelength switching. The testbed operates at 10 Gbps per channel. The effects of transmitter optical powers and the extinction ratios are numerically analyzed. Based on these results the system parameters, such as transmitter power and extinction ratio are optimized for the AON testbed.*

***Keywords:*** *Optimization, All-Optical Network, NRZ and RZ Modulation, WDM*

## 1. INTRODUCTION

In all-optical networks (AONs), the optical signal degradation and distortion seriously increases due to the deployment of wavelength-division multiplexing (WDM) technology and novel active/passive optical devices. Consequently the design and optimization of AONs have to take into account the effects of both noise and distortion related impairments on the performance of different modulation formats. The noise impairments include amplified spontaneous emission (ASE), receiver noise, laser noise, interferometric crosstalk etc. The distortion impairments are chromatic dispersion, polarization mode dispersion, non-linearity, crosstalk, and so forth [1]. Furthermore, some system parameters, such as the extinction ratio and output power of lasers at the transmitter, also put impacts on the modulation performance.

The non-return-to-zero (NRZ) and return-to-zero (RZ) formats are two well-known cost-effective candidates for the optimum modulation in AON. Generally, the RZ modulation may have better performance than NRZ due to a better match of the RZ pulses to the optical filter used at the receiver. On the other hand, the aforementioned noise and distortion impairments may suppress the RZ advantages [2]. Along this line, some papers have recently been published. For comparing various modulation formats, [3] set up a back-to-back configuration and thus the only considered impairment is ASE. In [5] and [6], some dispersion compensation schemes, such as the use of large mode fibre, non-zero dispersion-shift fibre (DSF) and dispersion-compensation fibre (DCF) are used to minimize the impacts of transmission impairments.

In this paper we pursue the same target, but in the context of a metro AON environment, without dispersion control/compensation. At the same time, we take into account the effects of novel active/passive optical devices, such as the photonic switches and erbium doped fibre amplifiers (EDFA), and the effects of system parameters including the transmitter power and extinction ratio.

The overall system performance of an AON metro WDM testbed is investigated by numerical simulation while using NRZ and RZ modulation respectively. Q-factor (equivalent to bit error ratio) is selected as the criterion for the comparison. The testbed operates at 10Gbps per channel and is based on commercially available photonic switches, which support dynamic wavelength switching. The effects of transmitter optical powers and the extinction ratios are numerically analyzed. Based on the simulation results, the system parameters, e.g. transmitter power and extinction ratio, are optimized for the AON testbed.

This paper is organized into sections. The specification and layout of the AON testbed is described in Section 2. The numerical simulation and optimization of NRZ- and RZ-modulation are discussed in Section 3. Based on the simulation results, some conclusions are drawn in Section 4. Future prospective work is also outlined.

## 2. SYSTEM SPECIFICATION

The testbed fulfills the AON functionality to be implemented involving key building blocks for an all-optical end-to-end WDM network. Such key building blocks include: photonic cross-connect (PXC), multiplexer

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(MUX), de-multiplexer (Demux), transmitter, receiver, and optical amplifier [1]. The specifications of the testbed are summarized in table 1. Note that there is no signal regeneration along the transmission stage, and no impairment compensation/control.

**Table 1. Summary of the Testbed Specification**

| | |
|---|---|
| System requirements | $BER \leq 10^{-12}$ , $Q \geq 7.5\,dB$ |
| Data rate per channel | 10 Gbps |
| Transmission distance | 30 km, typical for metro |
| Channel spacing | 200 GHz |
| TX output power | -3 dBm |
| PXC insertion loss | 2.5 dB |
| Mux/Dem insertion loss | 2.0 dB |
| Receiver sensitivity | -17 dBm |
| Extinction ratio | 10 dB |
| EDFA noise figure | 6.0 dB |
| Fibre loss | 0.2 dB/km |

The node and link configuration of the testbed is shown in Figure 1. It has 4 WDM channels in addition to a pair of add/drop channels. At the transmitters, the source signals (pseudo-random bit sequences) are modulated at 10 Gbps by external modulators (Mach-Zehnder). The modulated signals pass through a PXC with a pair of add/drop channels, and then they are multiplexed and coupled into a standard single-mode fibre. Finally the signals are de-multiplexed and pass through another PXC before they are detected with PIN receivers. The optical power ripple generated at an earlier stage in the network can be equalized by variable optical attenuators (VOAs) before the multiplexer and receivers respectively. An optical amplifier, an erbium doped fibre amplifier (EDFA) with the noise figure of 6.0 dB, is used for combating the optical attenuation in the transmissions. The PXCs are based on micro electro-mechanical system (MEMS) technology to provide strictly non-blocking photonic switching of fibre-optic traffic. Their switching time is less than 12 ms and the crosstalk below -50 dB.

For comparing the performance of NRZ and RZ modulation in the context described as above, the primary roles of numerical simulation are set as follows,

- Finding the effects on system performance of extinction ratios for all channels, under NRZ and RZ modulation respectively,
- Finding the effects on system performance of transmitter powers for all channels, under NRZ and RZ modulation respectively,
- Comparing the overall system performance under NRZ and RZ modulation with respect to ER and power respectively.

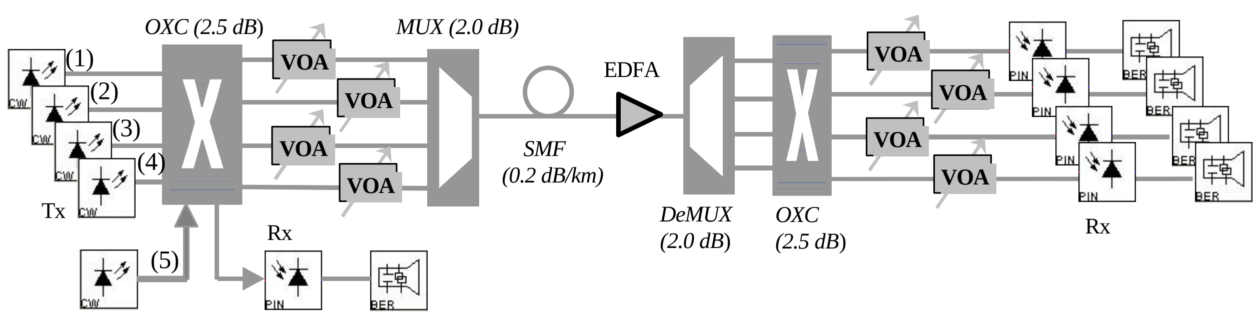


*Figure 1. Node and link configuration of the AON Testbed*

## 3. NUMERICAL COMPARISON OF NRZ AND RZ TRANSMISSION

In this section, the overall system performance of the testbed is evaluated by Q-factors (equivalent to BER). To accomplish the tasks described above, the effects on overall system performance of extinction ratio and optical power of transmitters are analyzed, using NRZ and RZ modulation formats respectively. For each scenario, the relationship between system performance (Q-factor) and system parameters (ER, TX power) is numerically analyzed and thus the system parameters are optimized under the given requirements ($Q \geq 7.5\,dB$) and the use of low-cost commercial available components. Furthermore, the end-to-end performances of typical WDM channels using NRZ and RZ modulation are compared.

In Figure 1, channel 3 is the cut-through channel (dropped) and the corresponding Q-factor is therefore not simulated. The Q-factors of all other 4 WDM channels are to be analyzed.

### 3.1 System Performance Study

The effects of extinction ratio on the system performance are investigated and the results are in Figure 2.

It shows that the system performance is improved (Q-factors increase) along with the increase of the extinction ratio (ER), in the case using either NRZ or RZ modulation format. In both cases the Q-factors increase almost linearly when $ER \leq 10\, dB$. However, when the ER exceeds a certain value (namely 12 dB here) the Q-factors increase gradually slowly. That means the system performance cannot be improved by increasing the ER unlimitedly. Therefore, considering the cost for increasing the ER, we find that the ER value is optimized to 10 dB for our particular AON testbed.

The relationship between Q-factors of WDM channels and transmitters' optical powers is numerically simulated and Figure 3 shows the results. For the worst channel, to satisfy the requirement of overall system performance, $Q \geq 7.5\, dB$, the optical power of the transmitter coupled into the link has to be more than – 4.5 dBm and – 5.5 dBm respectively for using NRZ and RZ modulation formats. Thus with considering the parameter specification of commercial available components and power budget margins, the transmitter's output power is optimized to – 3 dBm for this particular AON testbed.

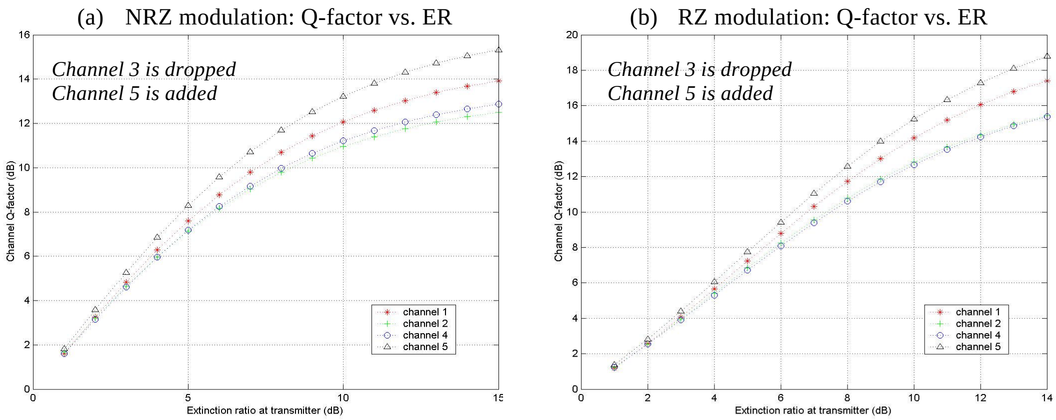


*Figure 2. Effects of extinction ratio on system performance (TX power = -3 dBm)*

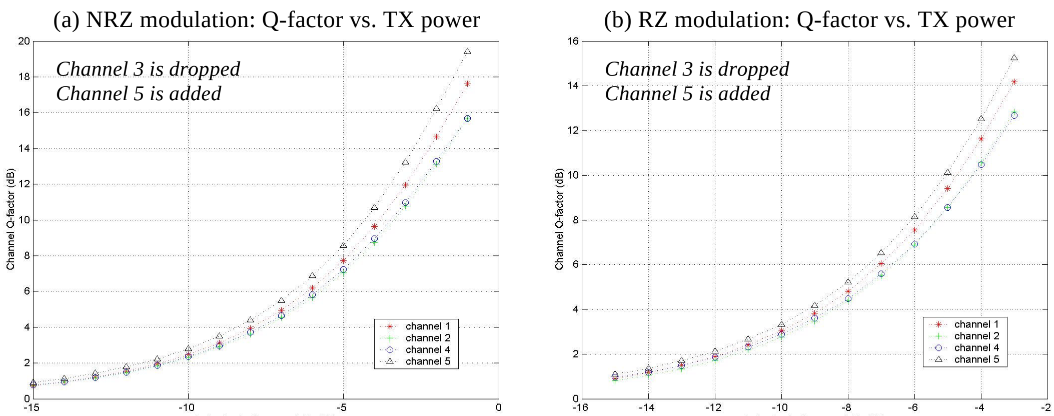


*Figure 3. Effects on system performance of transmitter power (extinction ratio = 10 dB)*

## 3.2 Performance Comparison for NRZ and RZ Modulation

The overall system performances when using NRZ and RZ modulation formats are compared for typical WDM channels. In Figure 4(a) the Q-factor of a typical channel (channel #2) is compared between using NRZ and RZ modulation, with respect to the extinction ratio. It shows that the NRZ modulation is slightly better than RZ modulation when the extinction ratio is low, though the difference is pretty small. This is due to that the transmission impairments have more suppression on the advantages of RZ modulation for low-ER signals than for high-ER signals. When the extinction ratio goes up and exceeds a certain value (6 dB), the performance of RZ modulation overtakes NRZ modulation and obtains about 2.5 dB Q-factor benefit at the optimized ER value (10 dB).

Figure 4(b) compares the performances of NRZ and RZ modulation for a typical WDM channel (channel #2) with respect to the transmitter power. Unlikely to the comparison with respect to ER, here the performance of RZ modulation always surpasses the NRZ modulation and the Q-factor using RZ formats is about 2.5 dB better than using NRZ formats, at the optimized power (namely -3 dBm here). This result indicates that the ER has a more important effect on the system performance than the transmitter power.

The comparison among other channels under the conditions of both Figures 4(a) and (b) are very similar to the results of channel #2 presented in the picture.

(a) Comparison NRZ-RZ (channel 2) Q-factor vs. extinction ratio

(b) Comparison NRZ-RZ (channel 2) Q-factor vs. TX power

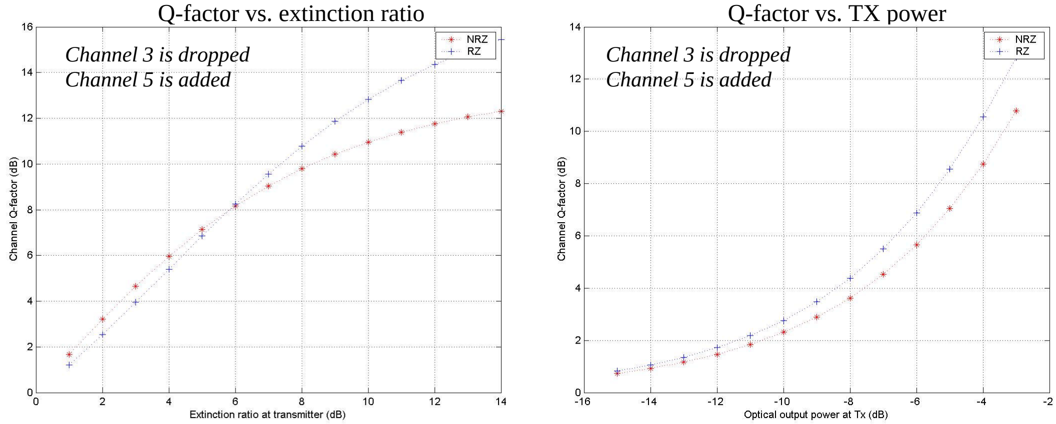


*Figure 4. System performance comparison: NRZ and RZ modulation*

## 4. CONCLUSIONS

The design and optimization of AONs must take into account the effects of system parameters on the performance of different modulation formats. In this paper the performance of NRZ and RZ modulation is investigated and compared under a particular AON testbed, with respect to transmitter power and extinction ratio respectively. The results show that when the ER is low, NRZ is slightly better than RZ but when the ER goes up the Q-factor under RZ modulation will be at least 2.5 dB better than under NRZ modulation with the optimized ER (10 dB). As for transmitter power, the performance of RZ modulation always surpasses the NRZ modulation and the Q-factor using RZ modulation is about 2.5 dB better than using NRZ modulation, at the optimized power (-3 dBm). This result indicates that the extinction ratio has a more important effect on the system performance than the transmitter power in the particular AON testbed.

The future work might include the similar study with increasing channel numbers and reducing channel spacing. Furthermore, the investigation of signal impairments and compensation, optical performance monitoring and fault management will be scheduled using the optimized testbed.

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## References


[1] Hongqing Zeng, Alex Vukovic, Heng Hua, J. Michel Savoie and Changcheng Huang, "Optimisation of All-Optical Network Testbed," *proceedings of the 3rd IASTED International Conference on Wireless and Optical Communications,* pp 75-79, July 2003

[2] D. Breuer, K. Ennser, and K. Petermann, "Comparison of NRZ- and Rzmodulation Formats for 40 Gbit/s TDM Standard-Fibre Systems," *in Proceedings of ECOC'96,* Paper TuD 4.4, Oslo, 1996

[3] G. Bosco, A. Carena, V. Curri, R. Gaudino, and O. Poggiolini, "On the Use of NRZ, RZ, and CSRZ Modulation at 40 Gb/s With Narrow DWDM Channel Spacing," *Journal of Lightwave Technology,* vol. 20, No. 9, pp 1694-1704, Sept. 2002

[4] Takeshi Hoshida, Olga Vassilieva, Kaori Yamada, Seemant Choudhary, Remi Pecqueur, and Hideo Kuwahara, "Optimal 40 Gb/s Modulation Formats for Spectrally Efficient Long-Haul DWDM Systems," *Journal of Lightwave Technology,* vol. 20, No. 12, pp 1989-1996, Dec. 2002

[5] B. Bakhshi, M. Vaa, E. A. Golovchenko, W. W. Patterson, R. L. Maybach, and N. S. Bergano, "Comparison of CRZ, RZ and NRZ modulation formats in a 64 x 12.3 Gb/s WDM transmission experiment over 9000km," *Proceedings of Optical Fiber Communication Conference and Exhibit,* vol. 3, pp WF4-1 -WF4-3, 2001

[6] O. Vassilieva, T. Hoshida, S. Choudhary, G. Castanon, H. Kuwahara, T. Terahara, and H. Onaka, "Numerical Comparison of NRZ, CS-RZ and IM-DPSK formats in 43 Gbit/s WDM Transmission," *LEOS 2001, The 14th Annual Meeting of the IEEE,* vol. 2, pp 673-674, Nov. 2001