3ème Conférence Internationale sur les Sciences Appliquées et l'Innovation (CISAI-2025)
Proceedings Book Series –PBS- Vol 25, 33-39

RZ and NRZ modulations impact on polarization mode dispersion in medium and long-distance optical links

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***Abstract*— Telecommunications optical networks are the many detrimental phenomena site related to the light polarization. The main issues include Polarization-Dependent Loss (PDL), Polarization-Dependent Gain (PGD), and Polarization Mode Dispersion (PMD), the latter being a phenomenon that results from the anisotropic propagation of the signal in optical fibers. PDL and PGD depend on the optical components used. The objective of this paper was to study the influence modulation format on the PMD emulator in medium and long-distance optical links, primarily using Optisystem software**

Keywords — **PMD emulator, modulation format, degree of polarization.**

I. INTRODUCTION

Polarization mode dispersion (PMD) results from two effects: birefringence, which locally causes a signals broadening propagating in the fiber, and mode coupling, which causes this broadening.

PMD has a direct impact on signal quality [1-7], which is why all parameters related to the performance of an optical communication link are used to estimate PMD: the Q factor, the eye diagram, the bit error rate, and the signal-to-noise ratio penalty (OSNR). Unfortunately, these parameters cannot be measured instantaneously; they require a relatively long time.

The Q factor, according to standards set in the telecommunications field, must be greater than 6, corresponding to a bit error rate (BER) of less than 10^{-9} [9, 11].

A spectrum analyzer is used to measure the differential group delay (DGD) by assessing certain characteristics related to signal distortions caused by PMD [12-13].

The measurement the Optical Degree of Polarization (DOP) as the feedback signal is based on the first-order PMD, observation which produces depolarization of the optical signal. The effectiveness of this technique depends on the ratio between DGD and bit time: if the DGD is greater than the bit time, a secondary maximum can be obtained via the DOP.

The degree of polarization is the polarization mode dispersion phenomenon.

II. SIMULATION

The results presented aim primarily to study the modulation format impact on the PMD emulator while specifying the received signal quality

ISSN: 2961-6611

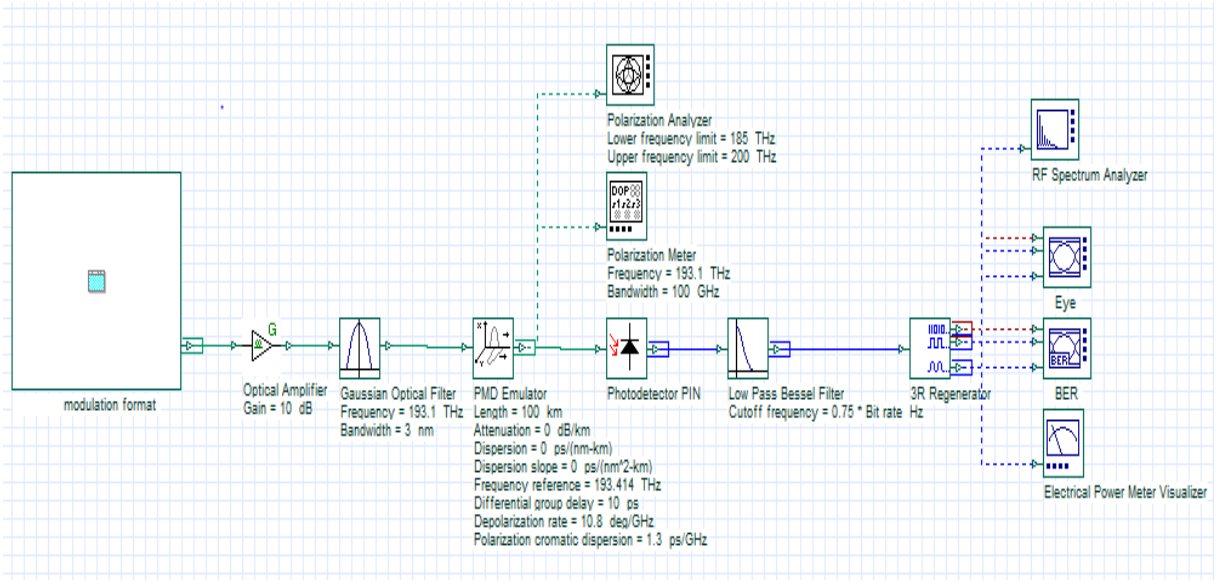
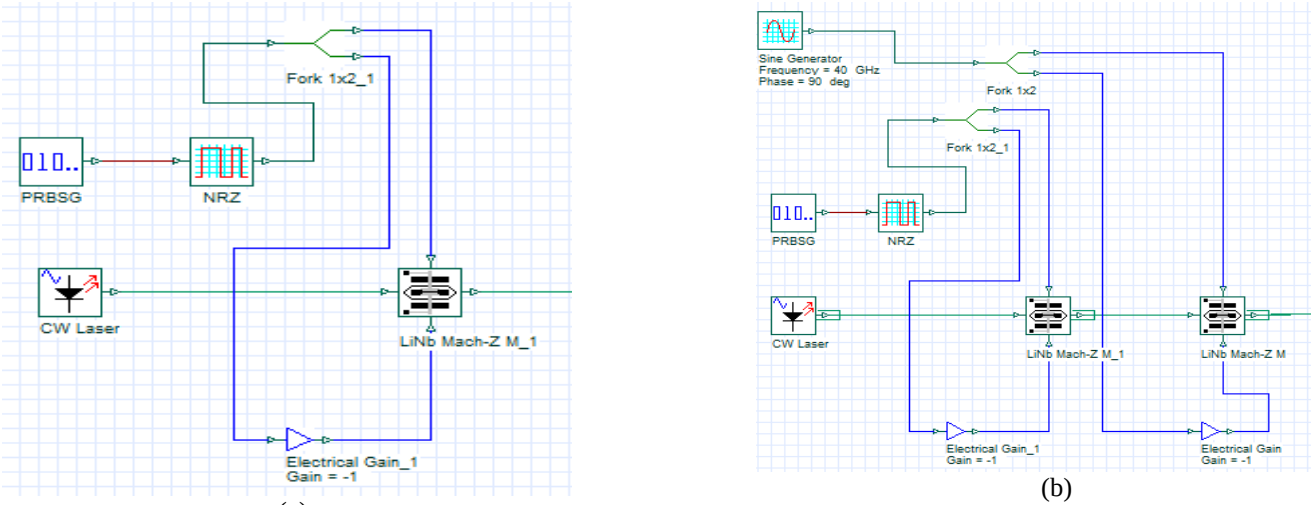


Fig1: Optical simulation chain

The two modulation formats are illustrated in Fig 02 below.



(a) (b)

Fig 2: (a) NRZ, (b) RZ modulation format

The NRZ modulation format is represented by Fig 2.a. The NRZ electrical signal encodes the optical signal using a Mach-Zehnder interferometer (MZI) intensity modulator. The output signal is an intensity-modulated NRZ optical signal at the data rate.

The RZ modulation format is represented by Fig 2.b. The NRZ optical signal is transformed into an RZ optical signal using a second modulator (MZI ($2V\pi$)) controlled by a sinusoidal signal with a frequency that is half of the data modulation rate. This modulator is called a pulse Shaper, as it shapes the pulses into the RZ format.

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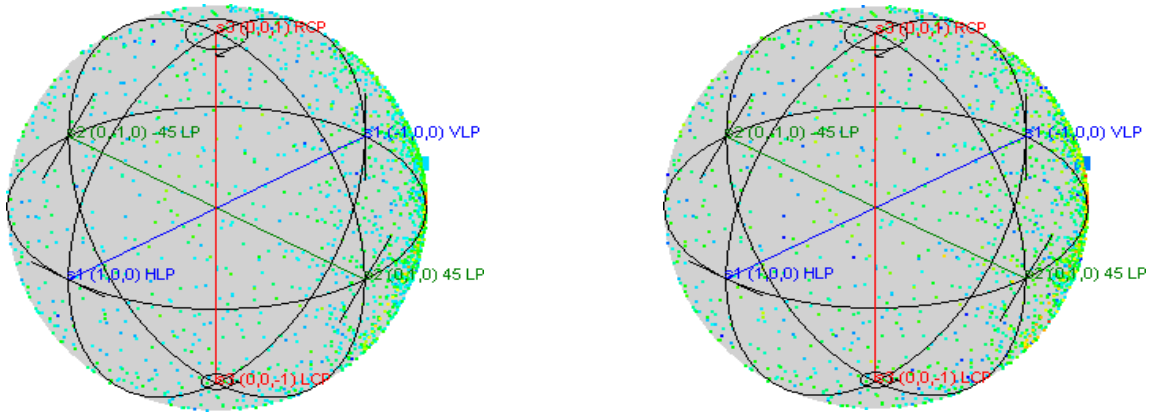
III. RESULT INTERPRETATION

1/ Poincaré Sphere



(a) NRZ code (DOP=50.89%) | (b) RZ code (DOP=54.48%)

Fig 3: Degree of Polarization.

The degree of polarization is a very important indicator of light polarization. According to Fig3, it is clear that the degree of polarization is sensitive to the modulation format used. The simulation results showed a DOP of 50.89% for the NRZ format, while the DOP was 54.48% for the RZ format.

In the case of the RZ modulation format, the signal energy is more confined to the each bit duration center. When Differential Group Delay (DGD) increases, the power in the isolated zeros rises only slowly. However, for the NRZ modulation format, this power increases quickly and combines with the ones, leading to more degradation.

Consequently, the pulse width varies depending on the bit configuration, while it remains the same in the case of the RZ format.

It is clear that the RZ modulation format is advantageous compared to the NRZ modulation format.

The DGD limits the degree of polarization. Fig 04 shows the DGD impact on the degree of polarization (DOP) for both modulation formats.

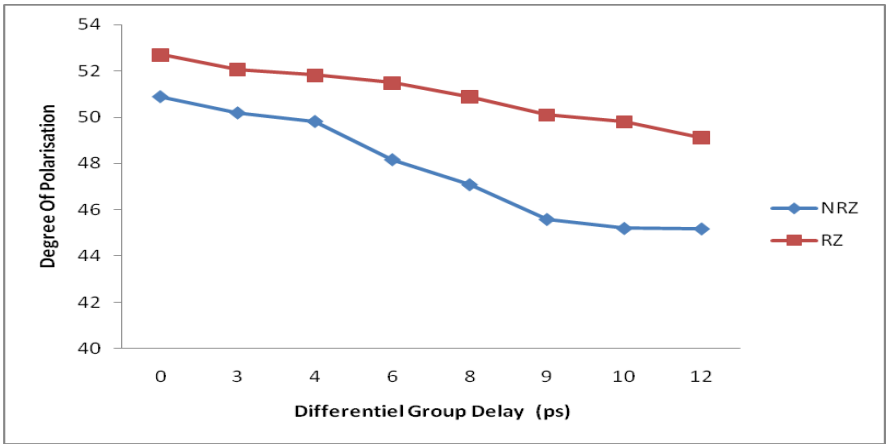


Fig 4: DGD Impact

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According to Fig 4, it is evident that as the delay between the principal polarizations states increases, the degree of polarization decreases. Indeed, polarization mode dispersion distributes the signal energy between two orthogonal polarizations over time-separated pulses when DGD is high.

2/ Fiber Length

Fig 05 shows the variation in fiber length for both modulation formats at a bit rate of 40 Gbit/s.

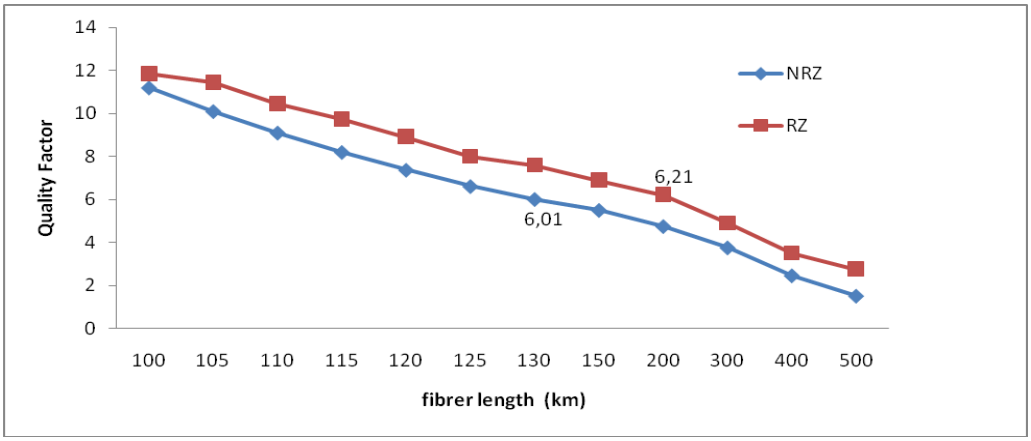

Fig 5: Length Impact

It is clear from Fig 05 that as the link length increases, the Q factor decreases, consequently leading to an increase in the bit error rate. For a Bit rate of 40 Gbit/s, the link lengths cannot exceed 129 km and 200 km, respectively, for the NRZ and RZ modulation formats in order for the system to maintain good quality (Q >= 6). For longer fiber lengths, and consequently larger differential group delay values, which are closer to the bit time of the data, PMD becomes a significant parameter in high-speed optical fiber transmissions, leading to degradation in transmission quality.

3/ Bit Rate

Fig 6 shows the variation in bit rate for both modulation formats at a fiber length of 129 km.

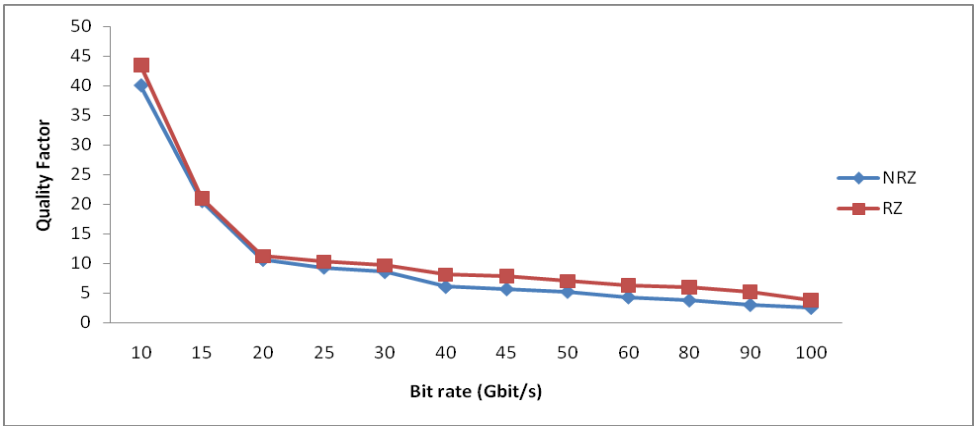

Fig 6: Bit rate Impact

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To maintain good transmission quality, the data rate should not exceed 40 Gbit/s for the NRZ modulation format and 60 Gbit/s for the RZ modulation format. Beyond these bit rates, the Q factor is degraded.

The bit rate remains the limiting factor for polarization mode dispersion in long-distance single-mode fiber.

In this case, the DGD is a random variable regardless of the data rate value, which means that the data rate does not influence the DGD.

4/SPANs Number

In this step, we replace the PMD emulator with the transmission line, as shown in the figure below.

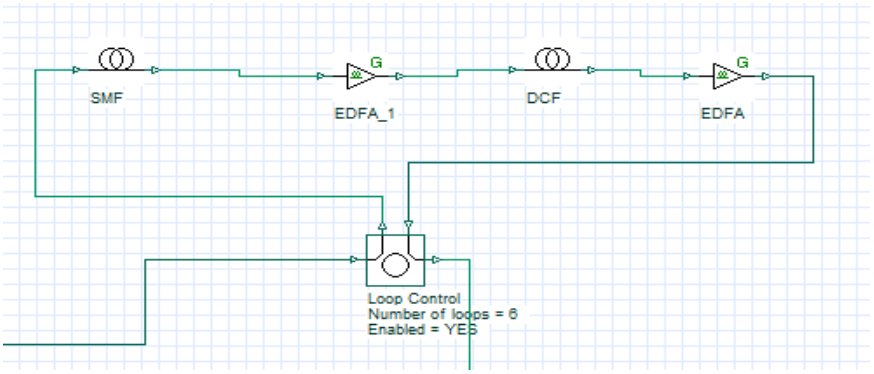

Fig 7: SPAN Structure

The feedback loop allows the signal to be looped. The results presented are from a link consisting of a 100 km standard G.652 (SMF) fiber followed by a 4 km dispersion compensation fiber (DCF) for both modulation formats.

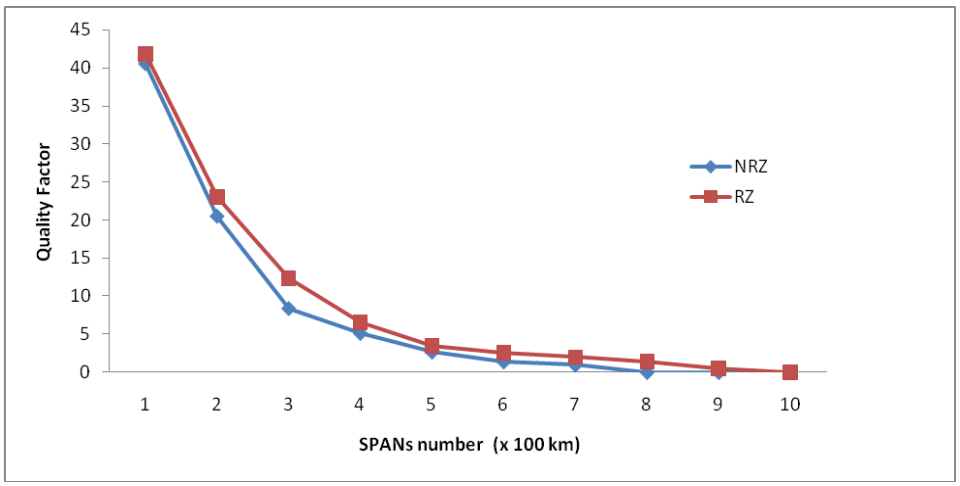

Fig 7: *SPANs number Impact*

According to Fig 7, it is noticeable that beyond 400 km (SPAN=4), the output signal quality is degraded for the RZ transmission module, which is advantageous compared to the NRZ modulation format.

ISSN: 2961-6611

In this case, the delay between the principal states polarization (PSP), in other words, the DGD, increases with the square root of the distance and the coupling length for both SMF and DCF fibers.

IV. CONCLUSIONS

The influence of polarization mode dispersion in medium and long-distance optical links was studied using Optisystem simulation tools. Several parameters that impact the performance of an optical link were highlighted. These simulation tools provide significant assistance in the design of high-speed systems.

The results obtained validated the choice of modulation formats and optical components. PMD is one of the most detrimental factors in optical telecommunications networks.

The simulation results indicate that PMD is a significant parameter for data rates of 40 Gbit/s and for SPAN lengths exceeding 400 km, with the RZ format being advantageous compared to the NRZ modulation format.

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ISSN: 2961-6611