

Transmitting audio via fiber optics under nonlinear effects and optimized tuning parameters based on co-simulation of MATLAB and OptiSystem™

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ABSTRACT

The ability of fiber optic to overcome the signal transmission problems is making it a dominant transmission medium. Despite of this major positive attribute of optic fibers, there is still a downside for using the fiber optic communication; that is the nonlinearity problem. For the first time, a design of an audio signal is suggested and executed in MATLAB with integration with OptiSystem™ Software. The audio signal then transmitted in different shapes of modulation signals (NRZ, RZ, & RC) for different distances (100 km & 75 km) via a fiber optic media to be received in a receiving part of the simulated system. Three tests are used to do so. The first is the Quality-factor (Q-Factor) against the received power, second test is eye diagram performance and finally is the measuring of the amplitude of output (received) signal for each modulation signal shape using the Oscilloscope Visualizer. The NRZ modulation signal was found to be the best one of the three used signals' types in all three tests. The Q-factor for NRZ pulse shape (=12) was higher than that for RZ (=10) and RC (=8) for a 100 km distance at the same received power level.

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1. INTRODUCTION

Since the optical fiber, as a communication medium, is providing a lot more bandwidth than the copper capacity, it is become the main communication systems medium [1-4]. It is offering low loss over a high bandwidth, reduction of unwanted alterations, no electromagnetic intervention, and its long life. Optical fiber and wireless communications are almost complementary, yet, especially at gigabits per second transmission rates, wireless network having some hindrance to accomplish high end-to-end data delivery performance. Optical fibers are widely used in communication, sensors, lighting and other usage [5-6]. In communication, optical fibers are providing a long distance and a higher data rates transmission comparing to other forms. Using copper wires in communication is less efficient than the optical fibers in long distances transmission besides the better immunity that the optical fibers provide against the electromagnetic interference. Optical fibers also provide a 100% signal security comparing to the copper cables [7-10]. The fibers are not emitted the transmitted signals without tampering while the copper cable dose, this fiber property preventing the drawing of transmitted signal. The non-linear behavior of optical fiber is its major weakness [11-20]. This nonlinearity is a directly proportional with the power of the signal been transmitted through the fiber optic. At the increasing of the light power, the nonlinearity behavior is becoming out of control and the probability of both distorting the transmitted signal and degrading the system efficiency may be raised [21-22]. There is also a higher chance of a signal interference as a result

of the non-linearity. When these signals are transmitted in an equally spaces' separated channels will create what is called the four-wave mixing (FWM). Suppressing the FWM in optical communication is improving the system efficiency, which is a high priority goal. Several techniques been done to achieve an effective reduction of FWM. Wavelength swept WDM, the allocation of polarization and effective frequency, WDM/TDM (wavelength/time division multiplexing), and non-uniform spacing of channels were applied [23-30]. These techniques are needing an extra complexity in system design or at least needing a compensator to improve the signal dispersion. Some of these techniques are negatively effecting the WDM capacity in order to compress the FWM.

The modulation technique used is influencing the signal's interference, which is occurring when FWM is used. The transmission of audio signal via optical fiber under the non-linear conduct is not yet investigated. The goal of this paper is to study the transmission of audio signal via fiber optic at a non-linear state and different modulation signals to find the best one for satisfied system performance. For this purpose, a system to simultaneously transmitting and receiving an audio signal via a fiber optic cable at its non-linear behavior is designed and implemented using the MATLAB and OptiSystem simulation model. The proposed system performance is tested for different types of modulation signals to get the best one.

2. MODELING OF AUDIO SIGNAL AND SIMULATION SYSTEM DESIGN

The system that designed for this work is highlighted in this section. It is simulated using MATLAB integrated with OptiSystem™. The simulated system of this work was designed and studied in three steps. The first is designing and implementing the new audio communication signal in MATLAB and integrated it into the OptiSystem™. The audio signal of the parameters shown in Table 1 then simulated with the fiber link as a second step. The third step is to study the performance of the optical signal under two transmission lengths (100 km and 75 km) for different pulse shapes modulation signals such as Non-Return-Zero (NRZ), Return-Zero (RZ) and RC (Raised Cosine). The design of the transmitter and receiver of the model is shown in Figures 1 and 2.

The transmitter part consists of an array of a continuous-wave (CW) produced by laser sources connected to an external modulator. The channel frequency is set to 193 THz. The external modulator is consisting of a Pseudo-Random Bit Sequence (PRBS) generator connected to a pulse generator to modulate the optical signals using different pulse shapes (NRZ, RZ, and RC) modulation signals which is connected to Mach-Zehnder modulator (MZM) acting as an intensity modulator. A single mode fiber is used as an optical link.

At the receiver, the de-multiplexer splits the collected frequencies. The PIN photo diode is detecting the signal with a responsivity (\mathcal{R}) of 0.8 A/W and a dark current of 10 nA. The signal is then passed through the low-pass Bessel filter, which is also linked, to the BER analyzer that is used to generate the graph. The system's parts (transmitter, optical channel and receiver) are shown in Figures 1 and 2, and its parameters are explained in Table 2.

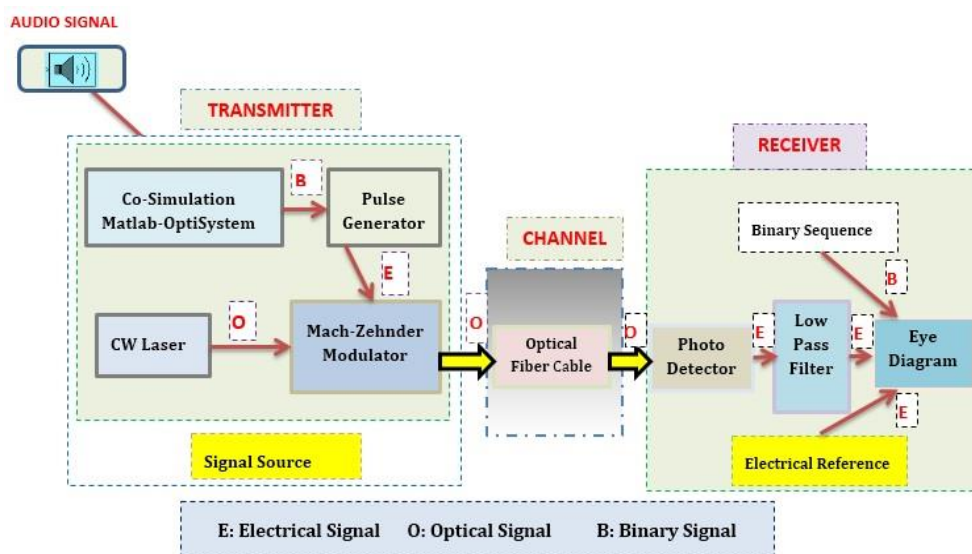


Figure 1. Full circuit diagram

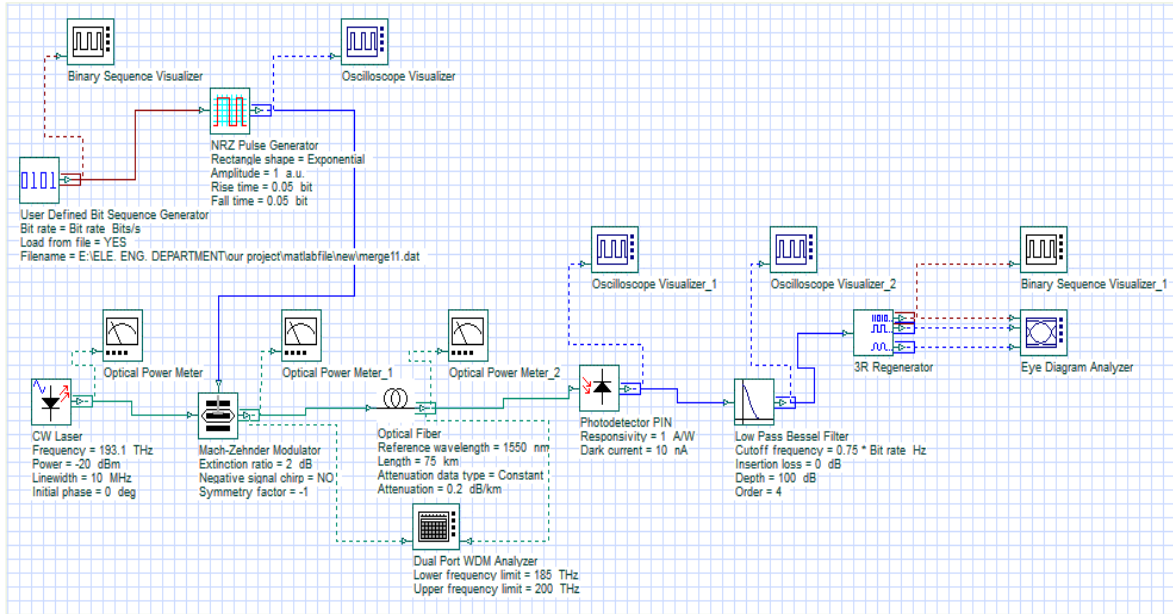


Figure 2. Optical simulation system design

Table 1. Audio signal properties

Parameter	Unit	Values
File Format	Wave Sound (.wav)	-
filename	story.wav	-
Bit Rate, B	kbps	141
Number of channels	n	2
Sample Rate, Fs	Hz	44100
Queue duration	Seconds	10
Frame size	Sample	1024
Output data type	double	-
Channel type	-	Stereo
load file to OptiSystem™	mat	-
Type of media path	Online media	-

Table 2. System parameters

Parameter	Unit	Values
Fiber length, L	km	75-100
Input power, Pi	dBm	(-20) to (-12)
Input frequencies	THz	193
Dispersion, Dc	ps/nm.km	17 for SMF
Dispersion slope S	ps/nm ² .km	0.075 for SMF
Cross effective area, Aeff	μm ²	80 for SMF
Third order susceptibility, X111	m ³ /w. s	6×10 ⁻¹⁵
Refractive index, n	-	1.48
Speed of light, c	(m/s)	3×10 ⁸
Attenuation factor,	(dB/ km)	0.2
Number of channels	-	1
Receiver noise temperature, Tn	K	300
Receiver load resistor, RL	Ω	1030

Schrödinger Equation (NLSE) is used to explain the envelope of the optical field when the nonlinear effects are in the form that is given by the following equation [12],

$$\frac{\partial A(z,t)}{\partial z} + \frac{\alpha}{2} A(z,t) + B_1 \frac{\partial A(z,t)}{\partial t} + \frac{j}{2} B_2 \frac{\partial^2 A(z,t)}{\partial t^2} - \frac{1}{6} B_3 \frac{\partial^3 A(z,t)}{\partial t^3} = -j\gamma |A(z,t)|^2 A(z,t). \quad (1)$$

where A, is the wave-field envelope, α is the fiber loss factor, B1, B2, and B3 are the dispersion factors and γ is the nonlinear constant.

To assess the system performance under the impact of nonlinear effect, which is the FWM crosstalk, and with other noise types, we should add the FWM crosstalk expressions as in (2),

$$C_{IM}^{(m)} = \frac{1}{8} \sum_I \frac{P_{ijk}}{P_s} + \frac{1}{4} \sum_{III} \frac{P_{iik}}{P_s} \quad (2)$$

where $C_{IM}^{(m)}$ is the FWM crosstalk effective in intensity modulation-direct detection (IM-DD) transmission. Note that the probability of transmit bit "1" at any time for every user is 1/2. Equation (3) explaining the relationship between the shot noise power (the left side) and the thermal noise power (the right side) [31]:

$$\sigma^2 = \frac{eB\mathfrak{R}P_{sr}W}{N} + \frac{4K_bT_nB}{R_L} \quad (3)$$

where, P_{sr} is a received peak power of the signal light, B electrical bandwidth of the receiver, \mathfrak{R} is the detector responsivity, e is the Electron's charge, K_b Boltzmann's constant, T_n Absolute receiver noise temperature, R_L Receiver load resistor. The average SNR (4) is calculated from (2) and (3) [31]:

$$SNR = \left[\frac{\left(\frac{\mathfrak{R}P_{sr}W}{N} \right)^2}{\frac{eB\mathfrak{R}P_{sr}W}{N} + \frac{4K_bT_nB}{R_L} + 2K^2P_s^2C_{IM}} \right] \quad (4)$$

Then BER is calculated in (5),

$$BER = P_e = \frac{1}{2} \operatorname{erfc} \left(\sqrt{\frac{SNR}{8}} \right), \quad (5)$$

and (6) is to find the Q-factor,

$$BER = \frac{1}{2} \times \operatorname{erfc} \left[\frac{Q}{\sqrt{2}} \right] \quad (6)$$

3. RESULTS AND ANALYSIS

This section is showing the finding of this work with analysis. The following results are obtained from the simulated system using transmission distances of 100 km and 75 km fiber length for 3- pulse's shapes NRZ, RZ, and RC for each distance:

3.1. Results of proposed system design using 100 km fiber length

3.1.1. Received power versus Q-factor

The relationship between the Received power and Q-factor under the effect of nonlinearity for different pulse shaping is shown in Figure 3. The optical input power is started at -20 dBm and increased by a step of 1 dBm till -12 dBm as a final input power. The obtained results are showing that the Q-factor is increased for the increasing in the received power for all shapes of pulses, however the system's behavior is different for different modulation signals under a nonlinear effect. The best value of Q-factor 12 was obtained when NRZ modulation signal is used at a received power of (-35 dBm). In the case of the RC modulation signal, Q-factor is a minimum (only in the range of 8) at the same received power (-35 dBm). For RZ pulses, the Q-factor is 10 which is in between the two previous values under the same conditions. This means that the NRZ gives a high resistance to the nonlinear effect in comparing with other two types.

3.1.2. Eye diagram performance

Figure 4 is showing the eye diagrams performances of the proposed system's approach taken at $ch1$ at $P_{in} = -14$ dBm. It is clear that using NRZ pulses, shown in Figure 4(a), is having wider eye opening which means a better performance and a higher invulnerability to noise comparing to the other two modulating signals as shown in Figures 4(b) for RZ and 4(c) for RC modulation signals.

3.1.3. Signal output behavior

Oscilloscope Visualizer is used to analyze and compare the electrical signals output for the 100 km fiber length of 3 types of modulation signals (NRZ, RZ, and RC). Figure 5 is showing that the optical system using NRZ, Figure 5(a), as a modulation signal is having higher power amplitude than the ones using RZ and RC, Figure 5(b) and 5(c). This means that the signal's power is higher than the noise power and this shall make the system's output at the receiver is more reliable and efficient.

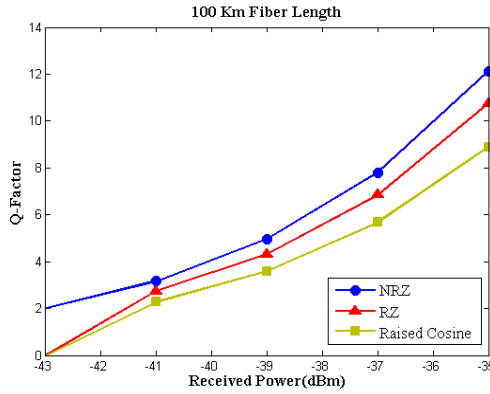


Figure 3. Q factor versus received Power at different pulse shape

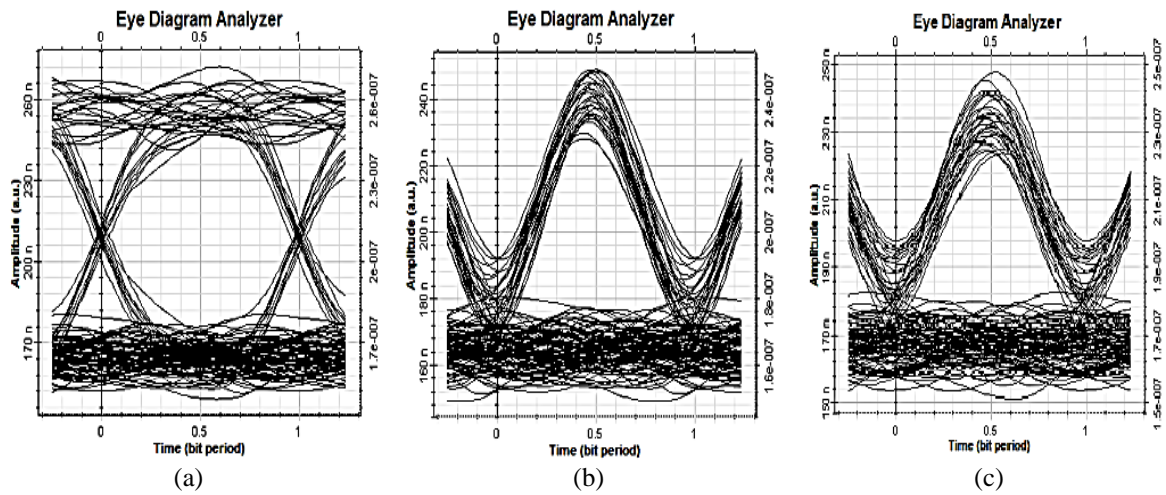


Figure 4. Eye diagram performance of 100 km length for (a) NRZ, (b) RZ, and (c) RC

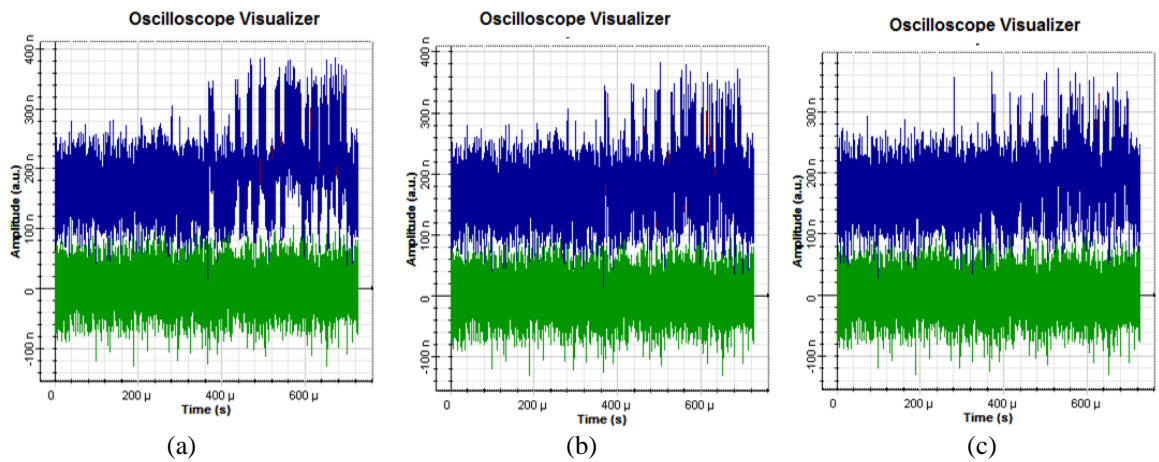


Figure 5. Signal output using oscilloscope visualizer of 100 km for (a) NRZ, (b) RZ, and (c) RC

3.2. Results of proposed system design using 75 km fiber length

By looking to the diagrams of Figures 6, 7, and 8, it is clearly showing that the results obtained for a 75 km transmitting are having the same conclusion for the 100 km distance. Figure 6 is showing that NRZ signal having the best Q factor comparing to the RZ and RC signals. Looking to Figure 7 is also showing the eye opening for NRZ is wider than for RZ and RC which means that using NRZ as a modulation signal is giving the best performance than using the RZ and RC. Figure 8 is giving the same finding that was from Figure 5, the Oscilloscope Visualizer is showing that the NRZ modulation signal is giving a higher signal amplitude power to noise amplitude power than the other two testing types (RZ and RC) modulation signals.

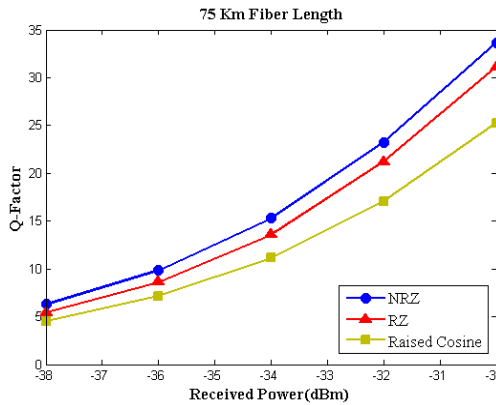


Figure 6. Q factor versus received power at different pulse shape

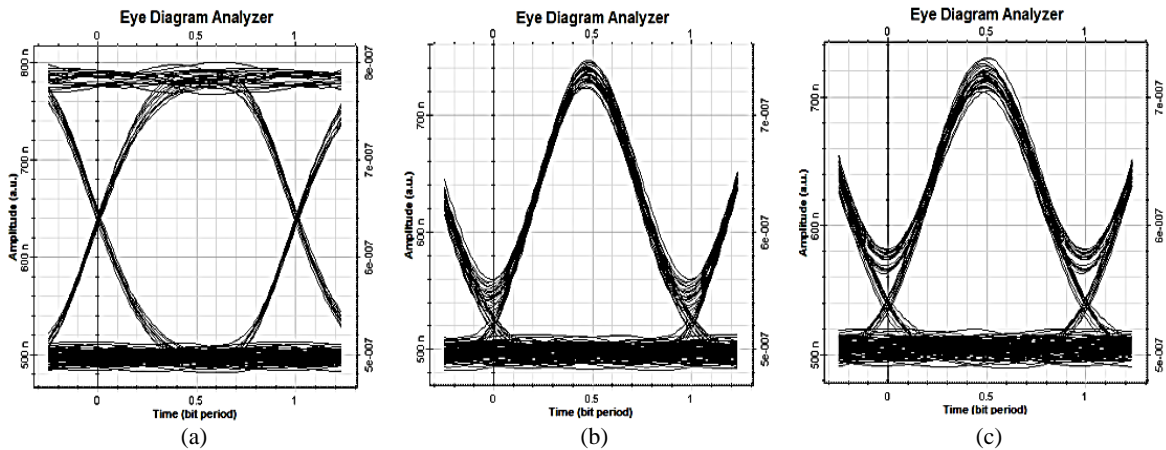


Figure 7. Optimum Eye diagram performance of 75 km length for (a) NRZ, (b) RZ, and (c) Raised cosine

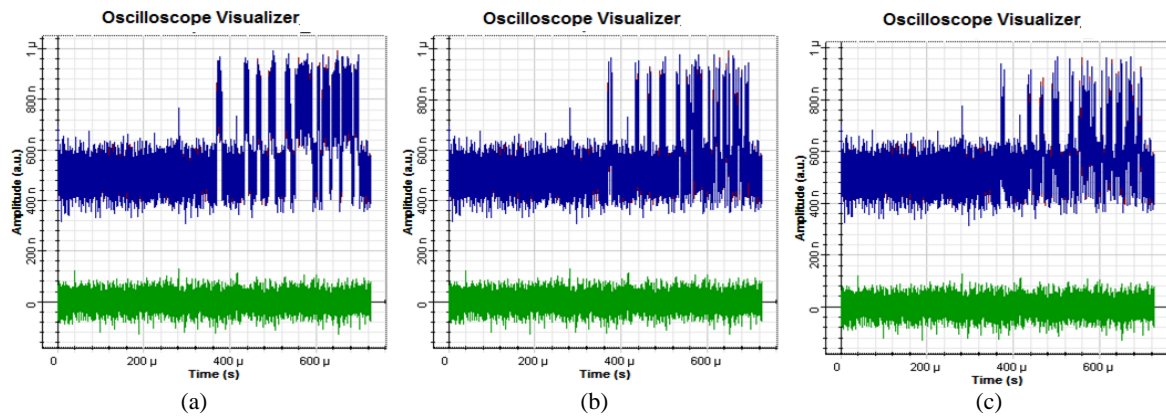


Figure 8. Signal output using oscilloscope visualizer of 75 km for (a) NRZ, (b) RZ, and (c) Raised cosine

4. CONCLUSION

The transmission of audio signal through Optical fiber system was designed and performed for first time using Co-Simulation of MATLAB integrated with OptiSystem14™. The system was tested for different types of pulse shapes (NRZ, RZ, and RC) modulation signals and for different distances 100km and 75 km of fibers lengths. Different parameters were studied and analyzed and the system was found to be having the best performance with NRZ modulation signal comparing to the other two (RZ and RC) for all three parameters and both distances. The Q factor, which is an efficiency indicator, is more when NRZ signal is used as a modulation signal 12 for a -35 dBm received power while it is 10 for RZ and 8 for RC at the same power for a 100 km of transmitting distance. The eye opening is also wider for NRZ than that for RZ and RC, which means that NRZ modulation pulse, is more resistive to noise. For a 75 km fiber transmitting distance, the conclusion has no difference than that for a 100 km distance. The eye opening in case of using NRZ as a modulation signal is wider than using other two types (RZ and RC). The Oscilloscope Visualizer is showing that the use of NRZ is having more confident than the use of RZ and RC because it is having a higher amplitude, which means that the ones and zeros of the received signals could be easily, differentiated when NRZ modulation signal is used comparing to the other two tested modulation signals (RZ and RC).

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