

Comparing the Performance of Optical Communication Link using G.652 and G.655 Fiber in Python Packages

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Abstract – This study investigates and compares the performance of a 10 Gbps optical communication link utilizing two prevalent single-mode fibers: G.652 and G.655. The analysis employs both theoretical calculations and Python-based simulations to assess the effectiveness of each fiber type in this high-speed transmission scenario. With the ever-growing demand for bandwidth in communication networks, 10 Gbps transmission systems are becoming increasingly commonplace. Single-mode fibers like G.652 and G.655 play a vital role in these systems, offering low signal attenuation for long-distance data transmission. However, each fiber type exhibits distinct dispersion characteristics, which can impact signal integrity over extended distances. This investigation adopts a two method for performance evaluation. Firstly, link power budget calculations are performed to determine the optical signal power before and after propagating through a 50-kilometer fiber span. The received power serves as the foundation for subsequent Q -factor and Bit Error Rate (BER) analysis. These calculations establish the theoretical limitations of the system based on well-defined formulas. Secondly, Python-based simulations are conducted to corroborate the theoretical findings and provide a more comprehensive performance assessment. This approach leverages the capabilities of two prominent Python packages: *Opticomlib* and *OpticommPy*. *Opticomlib* excels at analyzing the behavior of individual optical pulses within the system, enabling an understanding of the signal propagation. On the other hand, *OpticommPy* specializes in parameter sweep analysis, allowing for the investigation of how critical parameters like received power influence the Q -factor. By combining these functionalities, the simulations provide a detailed picture of the system's performance under various conditions. The calculated BER and Q -factor values for both G.652 and G.655 fiber links surpass the industry-accepted performance standards. These results demonstrate the effectiveness of using Python-based tools for comprehensive performance analysis of optical communication systems. However, it's important to note that slight discrepancies exist between the calculated and simulated results.

Keywords: Optical fiber communication; BER; Q -factor; *Opticomlib*; *OpticommPy*

INTRODUCTION

The use of optical fiber communication has been a great breakthrough and becomes a bridge to a brighter, connected future. Optical fiber networks are continuously installed in many parts of the world. The proses of designing fiber optics networks itself is not easy. Many factors need to be considered at physical layer, for example the optical fiber cabling, power, and performance. At other layer of Open Systems Interconnection (OSI) (Sullivan et al., 2021), more aspect needs to be considered. Optical communication design is now a multidisciplinary science

including laser science, photonic devices, fiber optics modeling, and digital signal processing. Optical communication research and development heavily relies on simulation software to conduct complex experiments that would be impractical or expensive in real-world settings.

Several optical simulation tools are available. Optisystem (Optiwave, 2024), Synopsys OptSim (Synopsys, 2024), and VPI (VPIphotonics, 2024) are the example of proprietary software that has large range of simulations. Optisystem and VPI are comprehensive, easy to use with helpful GUI and graph output relevant to every

measuring instrument, and capable to simulate almost all kinds of optical communication system. Matlab is also a powerful tool to simulate optical parameters of optical fiber communication. It mainly uses Simulink (Dama et al., 2020; Šalík et al., 2018) or external toolbox (Karapetyan, 2024; Steckler, 2017).

Open-source programming language such as Python can also produce simulation of optical fiber communication with proper preparation of the codes. Many previous instances use Python to create packages and often the codes are shared as libraries of reusable functions. Most python-based package does not offer a GUI with click, drag & drop. All the aforementioned python packages and modules depends on the user's capabilities to operate python codes and packages, such as numpy, scipy, and matplotlib.

Python packages have specific use for devices, either the fiber, amplifier, or laser. pyMMF (Popoff & Gostev, 2023) to find numerically the propagation modes and their corresponding propagation constants of multimode fibers. While PyFiberAmp (Rissanen, 2022) focuses on simulation related to fiber amplifiers and lasers. PyNLO (Ycas, 2015) and GNLSE (Pawłowski et al., 2020) package models the nonlinear interaction of light with materials, especially in optical fiber. Pyofss (Bolt, 2012) and Pyfmas (Melchert & Demircan, 2021) is more detailed and specific as it simulates z-propagation dynamics of ultrashort optical pulses in nonlinear waveguides. SuPyMode can handle optimization of fiber optic components (de Sivry-Houle et al., 2024).

Meanwhile, a more systematic approach is brought by NFDMLab (Brehler et al., 2019) where a performance analysis of single fiber optic link with frequency division multiplexing can be simulated. Pypho (Striegler, 2019) is a collection of

functions. With each function an object is defined which represents a network component such as transmission fiber, optical amplifier or laser diode.

Several papers show the design and evaluation of similar optical fiber backbone (Adiati et al., 2019; Herrera & Guerrero, 2023; Puttnam et al., 2021; Vergaray-Mendez et al., 2021). In real time, long-distance optical fibers (single mode) are tested and analyzed with the help of optical time domain reflectometer (OTDR) (Nandhakumar & Kumar, 2021) and BER tester. On the other hand, performance analysis also can be done using link power budget and rise time budget (Adiati et al., 2022; Azmi et al., 2021), and software simulation are still often used to calculate BER and Q-factor.

This paper explores the use of Python-based frameworks, OptiCommPy (da Silva et al., 2023) and Opticomlib (Romeu, 2024), for simulating a gigabit optical backbone using standard single-mode fiber and non-zero dispersion-shifted fiber. The performance of the simulated link will be evaluated using bit error rate (BER) and Q-factor analysis.

RESEARCH METHODS

The proposed optical fiber communication link is a backbone, with bit rate of 10 Gbps, using singlemode step-index G.652 (ITU-T, 2016) optical fiber as its media. Typical Optical Transport Network (OTN) Platform conforming ITU-T standard, operating in band-C is analyzed using Link Power Budget method and Python OptiCommPy simulation. Table 1 shows the parameter values used in calculations and simulation. The second case is the usage of G.655 (ITU-T, 2009) non-zero dispersion-shifted single-mode optical fiber.

Table 1. Parameter values of fiber communication link

Parameter	Values	Note
Order of the modulation format (M)	2	
Symbol rate (R_s)	10 Gb/s	
Pulse shape	NRZ	
Laser output power (P_i)	3 dBm	Equivalent to 1.99 mW
Min receiver sensitivity (P_{rx})	-28 dBm	
Total link distance (L)	varied	
Fiber loss parameter (α) (at 1550 nm)	0.35 dB/km	G.652
	0.2 dB/km	G.655
Fiber dispersion parameter (D) (at 1550 nm)	17 ps/nm.km	G.652
	3.5 ps/nm.km	G.655
Central optical frequency (F_c)	193.1 THz	corresp. to 1550 nm
Photodiode bandwidth (B)	10 GHz	
Simulation sampling rate (F_s)	160 GSamples/s	

Link power budget is a procedure in which one calculates maximum lost of power between the transmitter and the receiver. In the case of a backbone, the calculation is shown in equations 1 to 2 (Keiser, 2003).

$$\alpha_t = L \times \alpha_f + N_c \times \alpha_c + N_s \times \alpha_s \quad (1)$$

$$P_{Rx} = P_T - \alpha_t - SM \quad (2)$$

with,

- α_t : total loss (dB)
- L : fiber length (km)
- α_f : optical fiber attenuation (dB/km)
- N_c : number of connectors
- α_c : connector loss (dB)
- N_s : number of splices
- α_s : splice loss (dB)
- P_{Rx} : received power (dBm)
- P_R : receiver sensitivity (dB)
- P_T : transmitter power (dBm)
- SM : safety margin (dB)

Other parameters to evaluate the quality of an optical fiber link are Signal-to-Noise Ratio (SNR) and Bit Error Rate (BER), both can be represented by Q-factor or Q-parameter. SNR is the ratio between optical power detected at receiver with the noise power, while BER is also known as error probability. The formula to calculate SNR and Q factor is shown in equation 3 and 4.

$$SNR = 10 \log \frac{P_{\text{signal}}}{P_{\text{noise}}} \quad (3)$$

$$Q = \frac{2\sqrt{2} SNR}{1 + \sqrt{1 + 4SNR}} \quad (4)$$

RESULTS AND DISCUSSION

Link Power Budget Calculations

The link power budget analysis for a 50-km optical link is calculated in table 2. Different case, using G.652 fiber is calculated in table 3.

Table 2. Calculation of link power budget, G.652 fiber

Loss	calculation	Total loss (dBm)
α_f	0.35×50	17,5
α_c	0.25×2	0.5
α_s	0.1×50	5
α_{total}		23
P_T		3
P_R		-28
$P_{Rx} = P_T - \alpha_t - SM$		
$P_{Rx} = 3 - 23 - 6 = -26 \text{ dBm}$		
Power margin $-26 - (-28) = 2 \text{ dBm}$ (acceptable)		

Table 3. Calculation of link power budget, G.655 fiber

Loss	calculation	Total loss (dBm)
α_f	0.2×50	10
α_c	0.25×2	0.5
α_s	0.1×50	5
α_{total}		15.5
P_T		3
P_R		-28
$P_{Rx} = P_T - \alpha_t - SM$		
$P_{Rx} = 3 - 15.5 - 6 = -18.5 \text{ dBm}$		
Power margin $-18.5 - (-28) = 9.5 \text{ dBm}$ (acceptable)		

From the calculation in table 2, the power received in the other end of this communication link is (-26) dBm, about 0.0025 mW. The power margin is 2 dBm which means the link quality is acceptable. This variation of link is using central optical frequency of 193.1 THz of equivalent to 1550 nm wavelength. While G652 is a common fiber type, it's not optimized for minimizing dispersion at 10 Gbps over long distances like 50 km. Pulse dispersion causes pulses to spread out over time, potentially interfering with neighboring pulses and increasing the bit error rate.

In the second case (table 3), the fiber is upgraded into G.655 fiber, with very low value of dispersion shift, only 3.5 ps/nm.km compared to 17 ps/nm.km of G.652 fiber. The power margin obtained is 9.5 dBm, opening the possibility of reaching far more distances. If cost is not a consideration, long-distance communication links would utilize G.655 fibers.

The next analysis is Q factor calculation. Q factor is a measure of the quality of a digital signal in an optical communication system, that relates to Bit Error Rate (BER) and Signal-to-Noise Ratio (SNR). With equation 3 and 4, the value can be calculated.

It is noted that the SNR is calculated with the assumption that noise power is -50 dBm or about 10 nW. Noise of optical fiber communication can be comprised of thermal noise, the noise of electrical components due to electron movement in different temperatures, and shot noise, the fluctuation of photocurrent at optical receiver because photons are generated at random times. Table 4 shows the calculated SNR, Q factor, and BER of the proposed optical communication link.

Opticomlib simulation

Using Opticomlib simulation, the optical signal before and after propagating through optical fiber can be simulated. Figure 1 shows how the output signal decreases in both power and shape. The input signal is a single pulse with a power of 3 dBm (about 2 mW). Opticomlib has numerous options for signal generation because it has signal generator with customized bits, where user can select the bit data they want to send, or randomize some sequence.

After long propagation, the signal has much lower peak power at about 0.1 mW for G.652 fiber type, and 0.3 mW for G.655 fiber type. the decrease of power directly related to fiber loss parameter (α) or often called the fiber attenuation coefficient. Each fiber has different values of α for different wavelength.

Meanwhile, the shape of output signal is no longer a rectangular signal but becomes more gaussian or 'bell-like' curve. This is caused by the dispersion of signal, and directly proportional to the fiber dispersion parameter (D). The higher the dispersion value, the pulse broadening effect can be easily observed, and resulting in higher bit error rate (BER) values. Using the Opticomlib BER_analyzer function, the estimated BER values are 1.9×10^{-7} for G.652 fiber and 4.1×10^{-25} for G.655 fiber. The results are in accordance with the simple calculations result as shown in table 4. The simulation value shows lower probability of error in G.652 fiber. BER values are much lower when G.655 fiber is utilized, because it has lower value of dispersion. To be noted, BER values are not exact measurement and it can change every time the simulation is run because the pulse and signal used is randomized.

Table 4. Calculation and simulation of optical link parameters

Fiber optics	SNR	Q-factor		BER	
	(calc.)	Calc.	OpticommPy	Calc.	Opticomlib
G.652	24	6.257	7	$2,009 \times 10^{-10}$	1.9×10^{-7}
G.655	31.5	7.262	12	$1,948 \times 10^{-13}$	4.1×10^{-25}

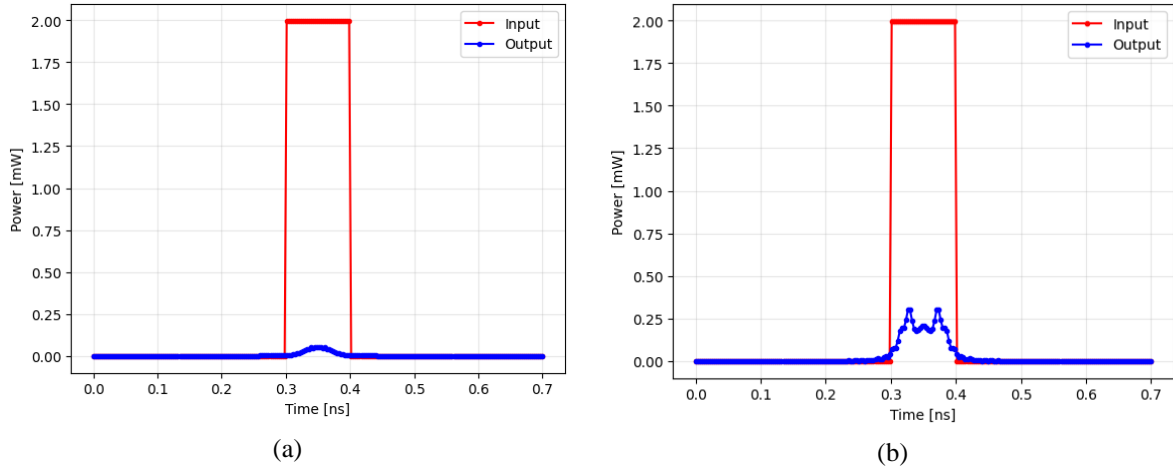


Figure 1. Opticomlib simulation: Sample optical pulse before and after passing through a 50-km optical fiber link in (a) G.652 (b) G.655 optical fiber

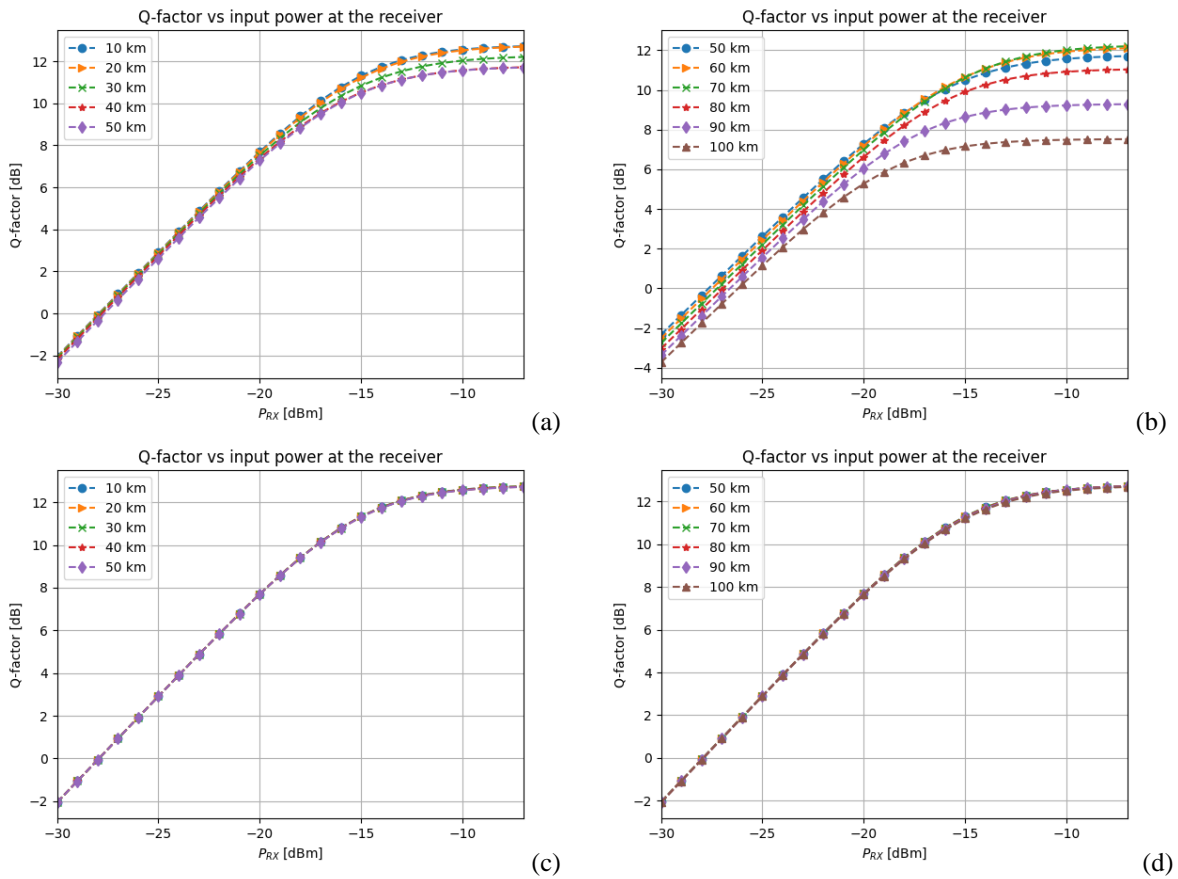


Figure 2. OpticommPy simulation: The Q-factor vs input power at the receiver at various link length and fiber type: (a) 10-50 km, G.652 fiber (b) 50-100 km, G.652 fiber (c) 10-50 km, G.655 fiber (d) 50-100 km, G.655 fiber

OpticommPy simulation

Similar to Opticomlib, OpticommPy has many packages to simulate different devices in the optical fiber communication links. However, where parameter sweeps are easier to do in OpticommPy. In these simulation, Q-factor of the optical fiber link is simulated with various length from 10 to 100 km. Figure 2 depicts the Q-factor vs. signal power at receiver input. Because Q-factor is in accordance to the signal quality, the values of Q increases when the received power is higher. Shorter link has better signal quality than the longer ones.

Figure 2 shows that for a 50-km link with power at receiver -18.5 dBm, the Q factor is higher than 8, confirming the calculation result at table 4 for both cases. However, the Q factor is different in values between calculation and simulation. This is because calculation only consider the signal power and assumed noise power as shown in equation 3 and 4, while in OpticommPy using on-off keying modulation and bit statistics, where the noise figure is considered.

For the G.655 fiber at figure 2 (c) and (d), the graphs are all adjacent to each other. Therefore, it can be inferred that the Q factor is not affected by the distance of the link, only by the input power to the receiver. This is not the case because the power received at the receiver is directly affected by the distance, as per link power budget calculation explained in previous section.

Q factor is not only affected by the signal power, but also the signal's BER, or pulse broadening. The higher the dispersion of a propagating signal, the Q factor will decrease.

CONCLUSION

Optical fiber communication links can be analyzed using python packages. OpticommPy and Opticomlib each has their

own interpretation and specialties in simulating optical fiber communication system. Both BER and Q factor obtained in calculation and simulation are above industry standards, but have different values due to the complexity of formula used in simulations. Notably, simulations provide deeper insights beyond calculations, revealing the impact of fiber type on pulse propagation and dispersion effects.

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