



Effect of Fiber-Telescope Coupling Losses on Wideband Wavelength Division Multiplexing in Free Space Optical Communications

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HIGHLIGHTS

- The Effect of TL on the performance of WDM-FSO is investigated.
- Wide Band WDM-FSO (C+L) is simulated utilizing hybrid fiber amplifier.
- High bit rate of 320 Gbps is achieved via 32 channels unidirectional (32 x 10 Gbps).

ABSTRACT

The effect of telescope losses (TL) on wideband wavelength division multiplexing (Wideband-WDM) based on free-space optical communication (FSOC) is investigated via OptiSystem software. In this work, both single and dual channel FSOC systems are investigated under different communication weathers: clear, haze, rain, and fog with attenuation losses of 0.2 dB/km, 2.3 dB/km, 4.3 dB/km, and 8.0 dB/km, respectively. The TL measures the coupling efficiency between the fiber and telescope in the transceiver assembly; therefore, is considered an important design parameter for the FSOC and hybrid optical communication system. According to the results, the maximum TL is 23 dB and 29 dB for single and dual FSOC, respectively, at the clear weather condition and for 1 km communication distance. This means that the dual-channel system could afford higher losses than the single system by approximately 26.1 %. Furthermore, this ratio is approximately the same for the other weather conditions, 28.6 %, 31.6 %, and 40 % for the hazy, rain, and fog weather, respectively.

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1. Introduction

The FSOC system utilizes the optical wave in visible and infrared regions as a carrier to the information signal [1-3]. This type of wireless communication system is combined with the radio frequency communication system to create a hybrid FSOC/RFC system or combined with the fiber optic communication system to make a hybrid FSOC/FOC system [4]. The FSOC is considered an alternative or complementary system that adds several features and advantages to the RFC and FOC system in both these hybrid systems. These advantages include ease of installation, low cost, and being free from collapse due to natural disasters, as the FOC system offers wide bandwidth when combined with the RFC system.

In this context, both single wavelength [5] and WDM [6-8] based FSOC systems were proposed and investigated under different weather conditions utilizing software and hardware procedures. But the published works for the latter (WDM-based FSOC system) were most theoretically works utilizing OptiSystem software [9-12]. This can be attributed to the high costly equipment and difficulty dealing with WDM issues based wireless systems in terms of; amplification and transceiver assembly. Based on works of literature, the most WDM-based FSOC was proposed and investigated within the conventional band. No works have investigated the TL as an important design parameter for the FSOC system. In this paper, a wideband-WDM-based single and a dual FSOC system were simulated and demonstrated under different weather conditions utilizing OptiSystem software. For the first time, the effect of the TL on both systems is investigated.

2. Experiment Setup

The proposed wideband-WDM-based FSOC system for both single and dual-channel are illustrated in Figure 1 (a) configuration A and (b) configuration B, respectively. In addition, the transmitter and receiver subsystems are depicted in Figure 1 (c) and (d), respectively. Table 1 contains the variables and constants adopted in both configuration systems.

2.1 Configuration A

Two scenarios operated the system in configuration A; the first scenario is represented by giving different and sequential values of the distance by 1 km in each reading, with the values of losses fixed at 0 dB seeking to know the maximum possible distance to be reached without losses. The second scenario was directed to work by fixing the distance value at 1 km and giving different and sequential TL values by 1 dB per reading. This is done to discover how much loss the system can bear before the point of collapse depending on the communications conditions (Q-Factor = 6 & BER = 1E-9), as shown in Figure 1 (a).

2.2 Configuration B

The system in Configuration B was operational with the same working scenarios in configuration A. Still, the difference in this configuration was to add an FSOC channel to Configuration A to find the percentage of improvement achieved when using the dual FSOC channel in both scenarios, as illustrated in Figure 1 (b).

3. Results and Discussion

The results of this work were divided into two categories, namely, the performance of proposed systems without and with TL. The Q-Factor of 6 and BER of 10E-9 are adopted as the communication condition in this paper.

3.1 Performance characteristics without TL

In this work, the TL is fixed at 0 dB, and the maximum communication distance is determined for several weather conditions. The performance parameters of wideband-WDM-based single-FSOC systems are investigated under different weather conditions without TL, namely, clear, haze, rain, and fog, as illustrated in Figures 2, 3, 4, and 5, respectively. The maximum obtained distance at communication conditions is about 13 km, 4.8 km, 3.3 km, and 2.3 km for the weather conditions of clear, haze, rain, and fog, respectively. Furthermore, the performance of the dual-FSOC system is depicted in Figures 6, 7, 8, and 9. Based on the literature, the dual system enhances communication distance. For the proposed system, the enhancement in the communication range was about 61.5%, 35.4%, 30.0%, and 17.4% for the weather conditions of clear, haze, rain, and fog, respectively. The summarizes the performance of both designs without TL is illustrated in Table 2.

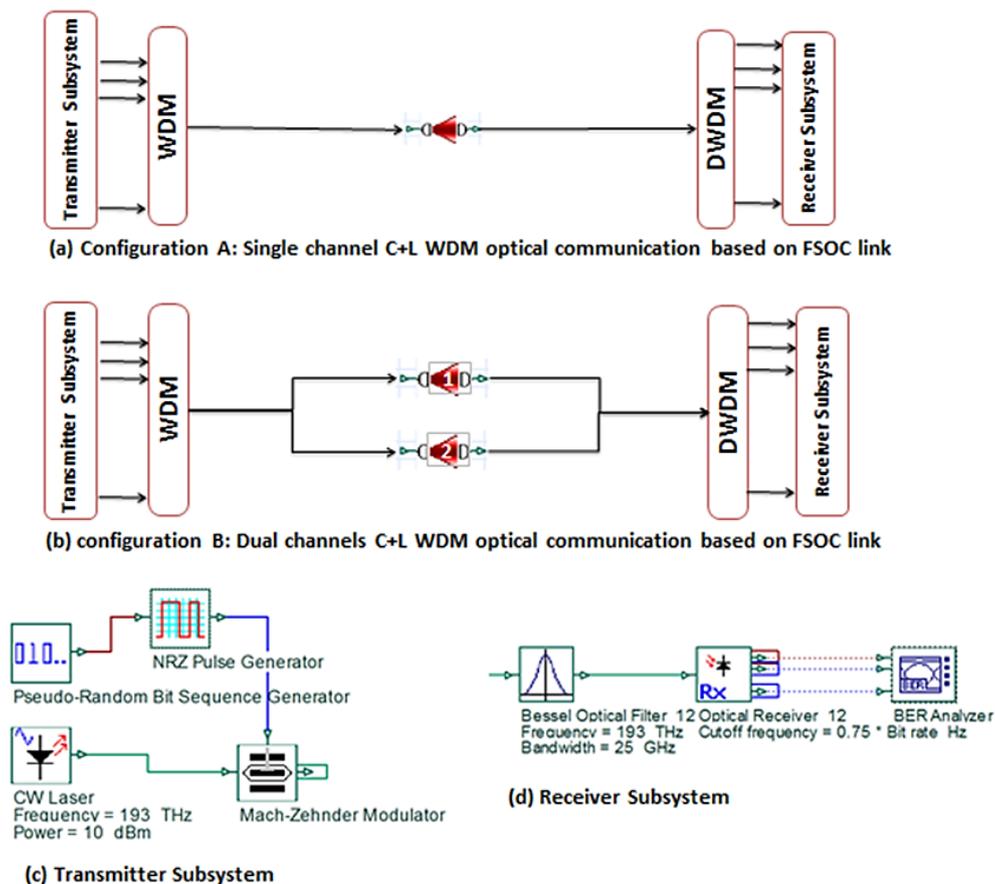


Figure 1: (a) Configuration A: Single channel C+L WDM optical communication-based FSOC link, (b) Configuration B: Single channel C+L WDM optical communication-based FSOC link, (c) Transmitter subsystem, and (d) Receiver subsystem

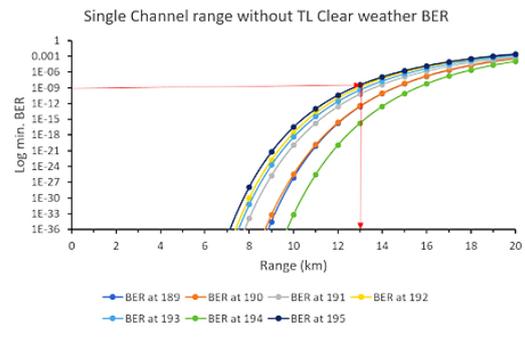
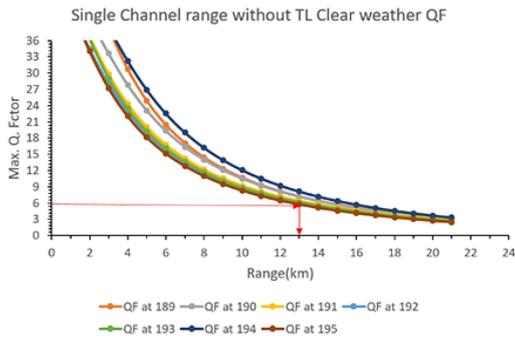


Figure 2: The performance of a single channel without TL at clear weather (a) Q-Factor and (b) BER

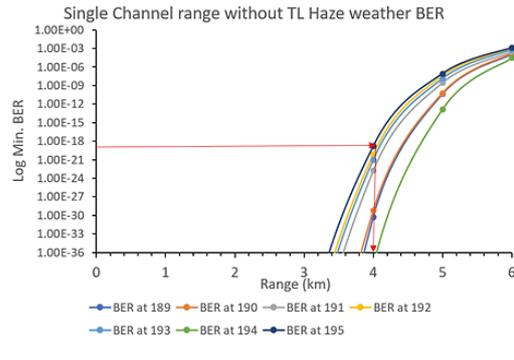
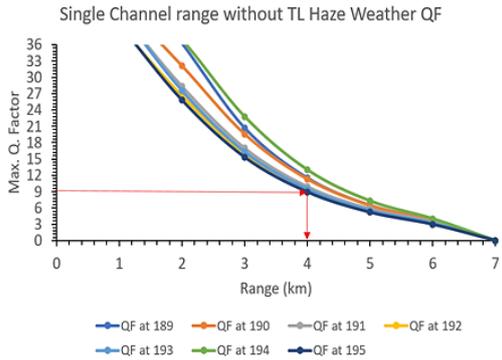


Figure 3: The performance of a single channel without TL at hazy weather (a) Q-Factor and (b) BER

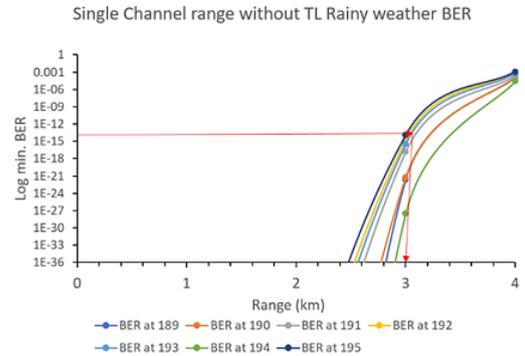
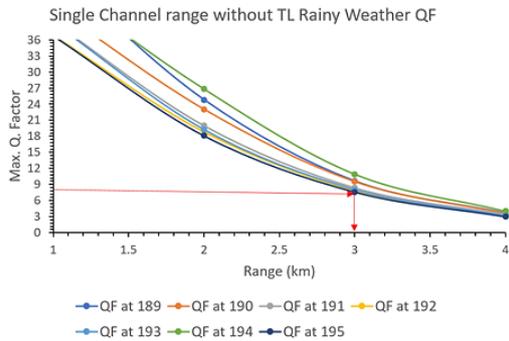


Figure 4: The performance of a single channel without TL at rain weather (a) Q-Factor and (b) BER

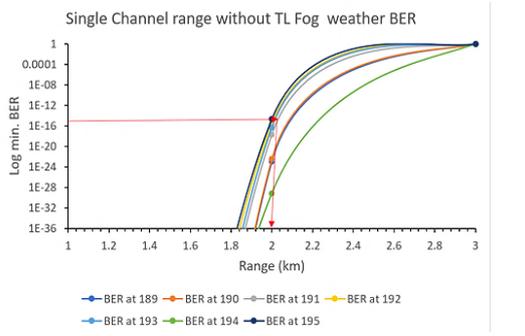
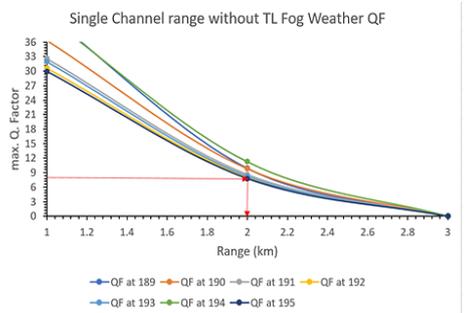


Figure 5: The performance of the single-channel without TL at fog weather (a) Q-Factor and (b) BER

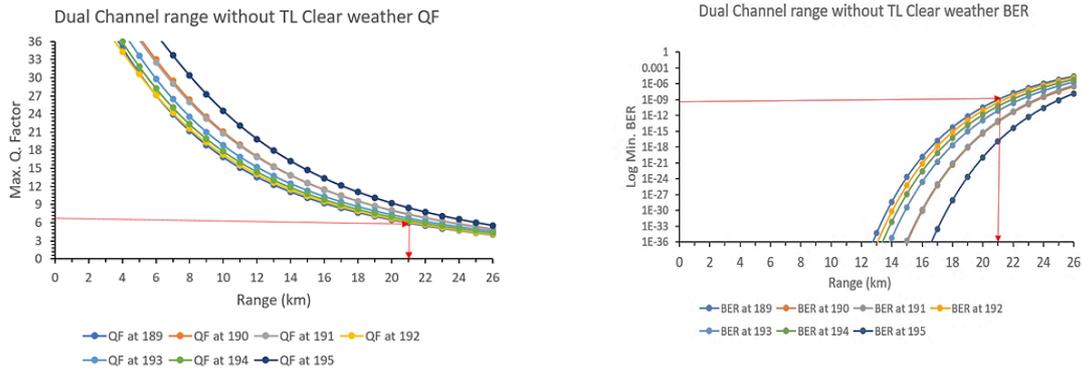


Figure 6: The performance of Dual-channel without TL at clear weather (a) Q-Factor and (b) BER

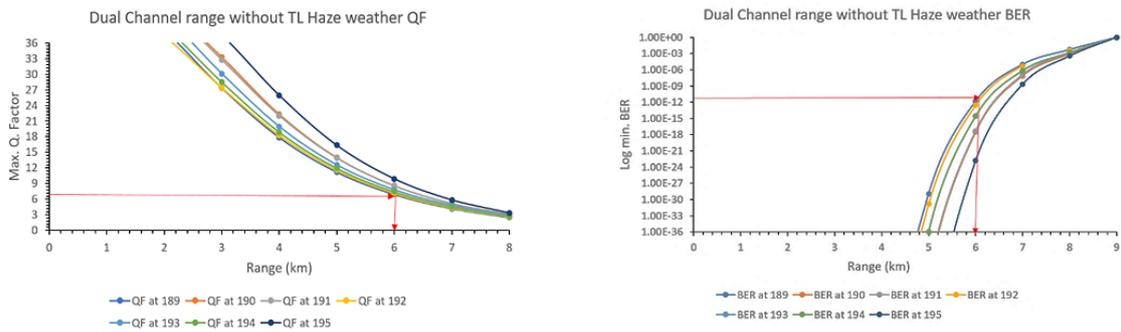


Figure 7: The performance of the dual-channel without TL at haze weather (a) Q-Factor and (b) BER

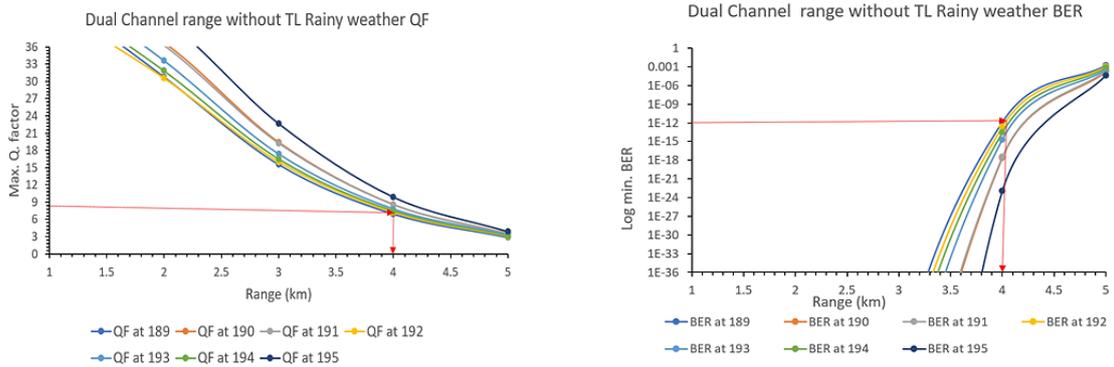


Figure 8: The performance of the dual-channel without TL at rain weather (a) Q-Factor and (b) BER

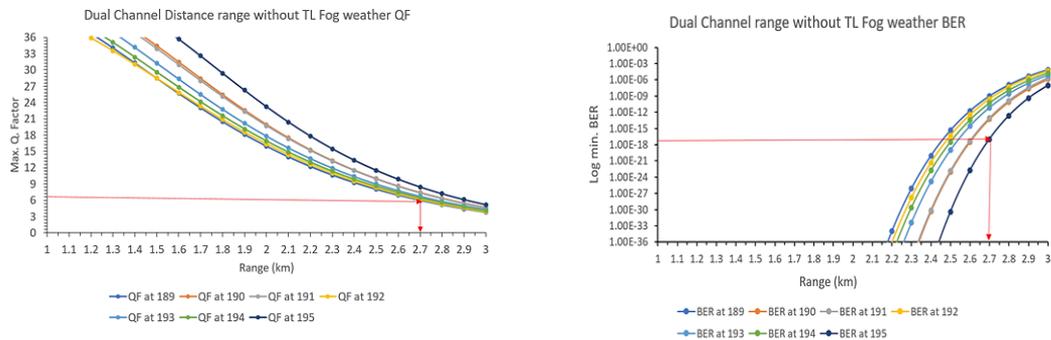


Figure 9: The performance of the dual-channel without TL at fog weather (a) Q-Factor and (b) BER

3.2 Performance characteristics with TL

In this section, the communication distance is fixed at 1 km, and the TL is determined under several weather conditions for both systems. The performance of wideband-WDM-based single-FSOC systems are investigated under different weather conditions at the 1 km communication distance, namely, clear, haze, rain, and fog, as illustrated in Figures 10, 11, 12, and 13, respectively. In addition, Figures 14, 15, 16, and 17 depicted the performance of wideband-WDM-based dual-FSOC systems under different weather conditions at the 1 km communication distance, namely, clear, haze, rain, and fog, respectively. The maximum TL is about 23 dB, 21 dB, 19 dB, and 15 dB for the weather conditions of clear, haze, rain, and fog, respectively. While, for the dual system, the maximum TL is about 29 dB, 27 dB, 25 dB, and 21 dB for the weather conditions of clear, haze, rain, and fog, respectively. This represents an enhancement in the maximum TL value of about 26.1 % for clear, 28.6 % for haze, 31.6 % for rain, and 40 % for fog. The summary of both designs' performance with maximum TL is illustrated in Table 3.

Table 1: System design parameters that are adopted in this work

Transmitter	Value	FSO	Value
Bit rate	10 Gbps	Transmitter diameter	15 cm
Power	10 dBm	Receiver diameter	20 cm
Linewidth	10 MHz	Beam divergence	1 mrad
Frequency	189–195.3 THz	Misalignment loss (ML)	0 dB
Space	100 GHz		

Table 2: The performance for the dual-channel with TL at fog weather (a) Q-Factor and (b) BER

Weather Condition	Single FSO channel			Dual FSO channel			Enhancement
	Range km	Q-Facor	BER	Range km	Q-Facor	BER	
Clear at 0.2 dB/km	13	5.61911	7.27E-09	21	5.96	9.28E-10	61.5%
Haze at 2.3 dB/km	4.8	5.78597	2.72E-09	6.5	5.78	2.90E-9	35.4%
Rainy at 4.3 dB/km	3.3	5.7749	2.90E-09	4.3	5.73	3.67E-9	30.0%
Fog at 8.0 dB/km	2.3	5.71704	4.09E-09	2.7	5.97	8.86E-10	17.4%

Table 3: Summarizes the performance of both designs with maximum TL for a communication distance of 1 km

Weather Condition	Single FSO channel			Dual FSO channel			Enhancement
	TL dB	Q-Factor	BER	TL dB	Q-Factor	BER	
Clear at 0.2 dB/km	23	6.18	2.30E-10	29	6.20154	2.07E-10	26.1 %
Haze at 2.3 dB/km	21	6.10	3.90E-10	27	6.11876	3.49E-10	28.6 %
Rainy at 4.3 dB/km	19	6.10	3.90E-10	25	6.11876	3.50E-10	31.6 %
Fog at 8.0 dB/km	15	6.36	7.81E-11	21	6.36982	6.97E-11	40.0 %

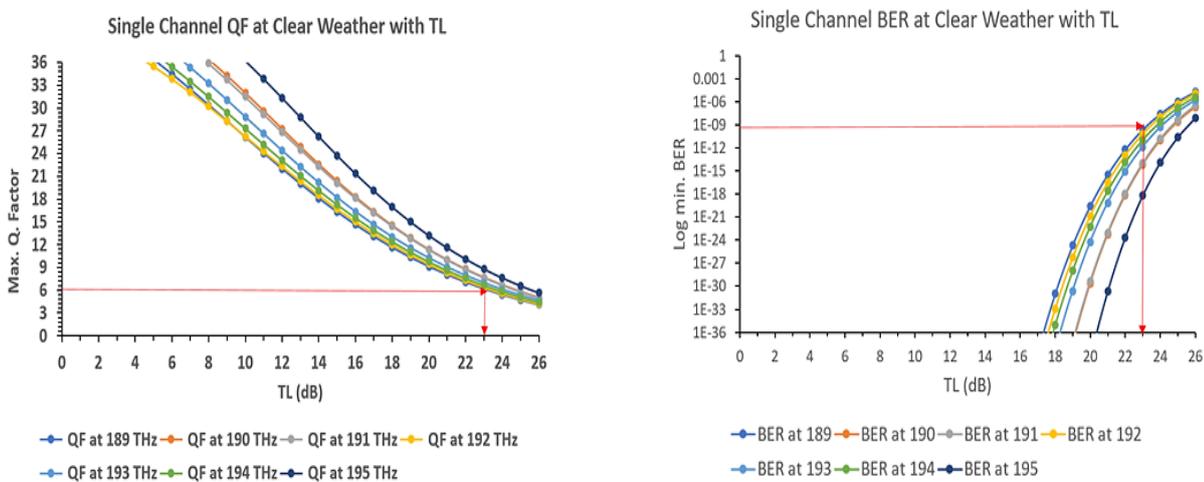


Figure 10: The performance of a single channel with TL at clear weather (a) Q-Factor and (b) BER

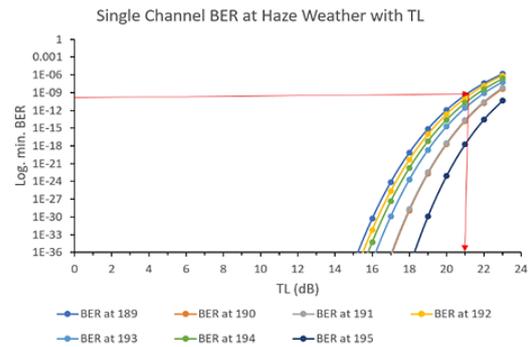
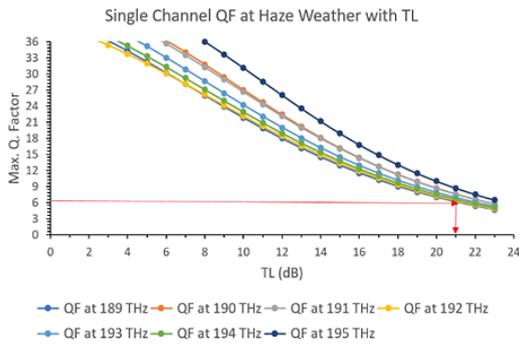


Figure 11: The performance of a single channel with TL at hazy weather (a) Q-Factor and (b) BER

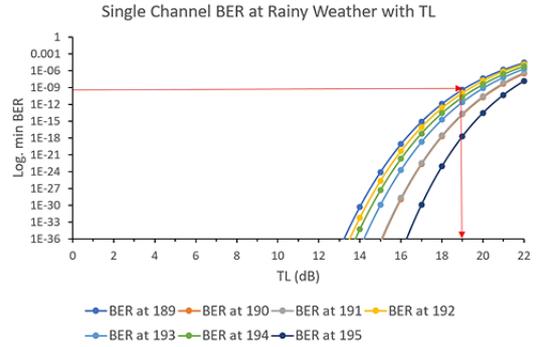
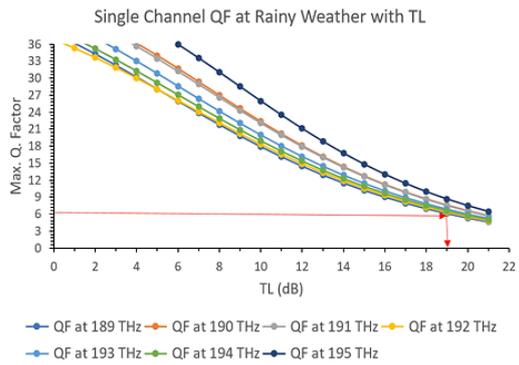


Figure 12: The performance of the single-channel with TL at rain weather (a) Q-Factor and (b) BER

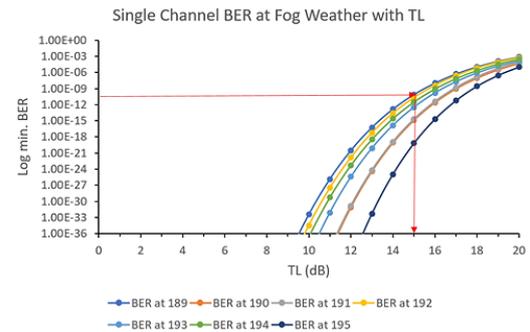
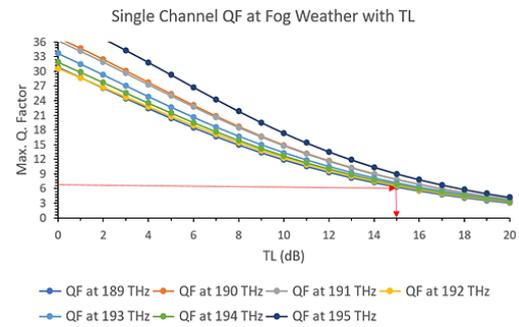


Figure 13: The performance of the single-channel with TL at fog weather (a) Q-Factor and (b) BER

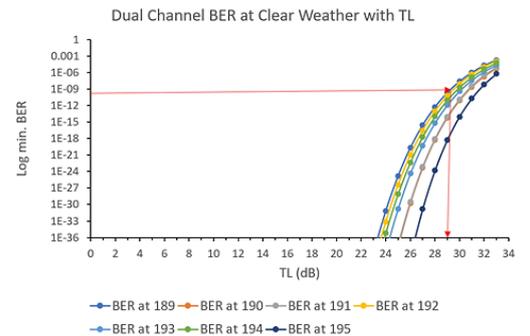
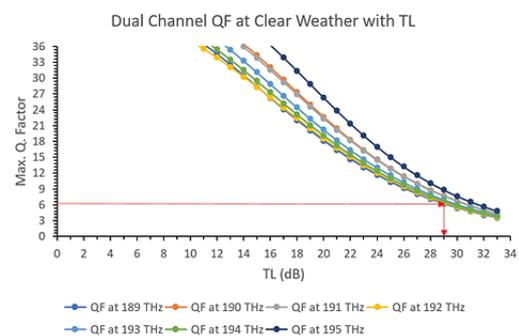


Figure 14: The performance of the dual-channel with TL at clear weather (a) Q-Factor and (b) BER

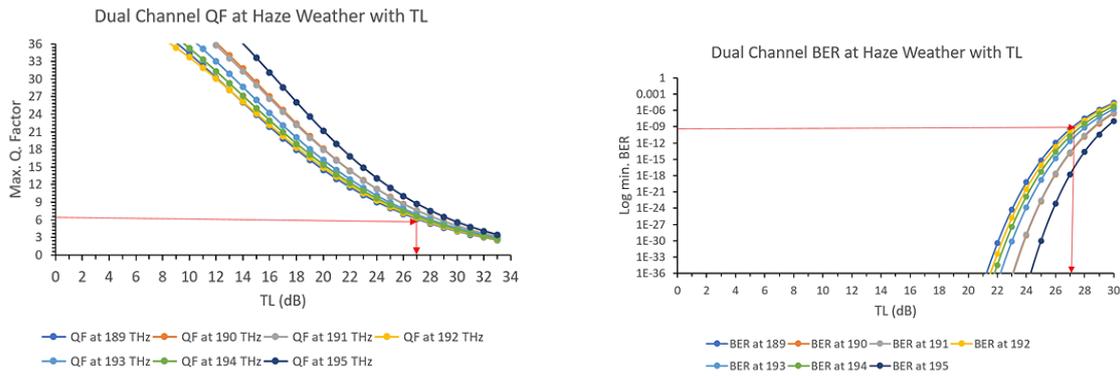


Figure 15: The performance of the dual-channel with TL at haze weather (a) Q-Factor and (b) BER

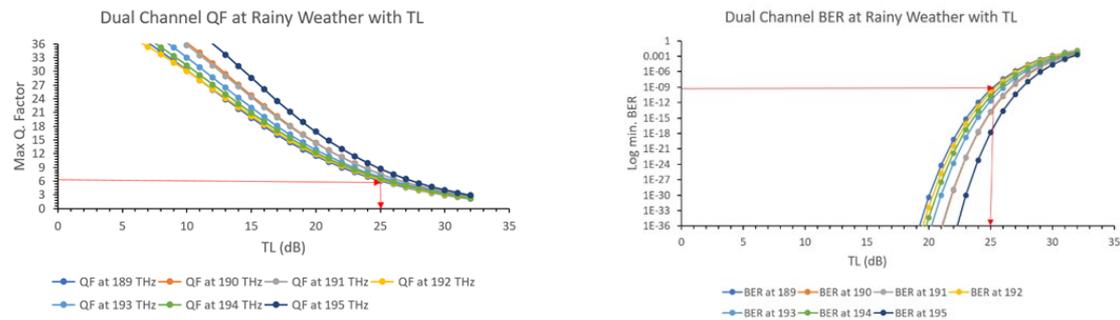


Figure 16: The performance of the dual-channel with TL at rain weather (a) Q-Factor and (b) BER

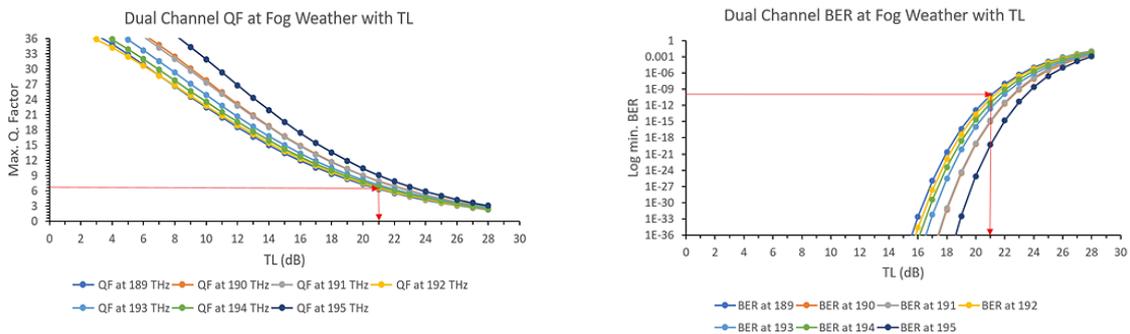


Figure 17: The performance of the dual-channel with TL at fog weather (a) Q-Factor and (b) BER

4. Conclusion

The Wideband-WDM-based single and dual FSOC systems were simulated and demonstrated under different weather conditions utilizing OptiSystem software. Furthermore, the effect of the TL on both systems is investigated. In this paper, the maximum TL for at the communication distance of 1km was determined for the first time to the best of our knowledge. The results show that the dual system offers a longer communication distance and bears higher TL than the single channel under different weather conditions.

Author contribution

All authors contributed equally to this work.

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Data availability statement

The data that support the findings of this study are available on request from the corresponding author.

Conflicts of interest

The authors declare that there is no conflict of interest.

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