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Investigation of Multiple Transceiver System for Free Space Optical Communication

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Abstract: In free space optical (FSO) communication, atmospheric turbulence has major impact on the stability of a free space optical transmission system. Laser beam with high coherency and intensity is commonly used to increase the transmission distance. However, with an increased distance, the stability of the system becomes more sensitive to the turbulence. In this work, a multiple transceiver system with signal summing approach is implemented to improve signal transmission stability. The performance of the proposed system is investigated with the intensity turbulence modeled. In comparison with the single transceiver system, the proposed system showed higher signal-to noise ratio and lower bit-error-ratio with doubled stability in terms of the improvement factor.

Keywords: Free Space Optical, multiple transceiver, atmospheric turbulence, laser beam signal transmission

1. Introduction

Laser in free space optical (FSO) communication is license free and could improve transmission range due to property of coherent and high intensity beam [1]. However, atmospheric turbulence is the current limitation of most FSO system which trigger irradiance fluctuations which is known as scintillation along the propagation path [2]. Scintillation occurs when a transmitter located at a distance from receiver, the intensity of detected signals fluctuates due to the changes of refraction index of the air along the transmission pathway [3]. The changes in refraction index affect the atmosphere to create series of small lenses which deflect transmitted beam in and out of the transmission pathway. On a shiny day, FSO system may be affected by the turbulence fading. Due to temperature fluctuations above hot surfaces [4], tiny air cells with various densities, temperatures and level of refraction are present in such situation. Fog, haze, snow or rain are conditions known as the atmospheric attenuation [5]. Such atmospheric attenuation causes scattering, absorption and deviations of laser signal in the transmission pathway [6].

The temperature of air experienced gradient change which induced by solar radiation and wind; hence it produces random inhomogeneities in particles of air. This phenomenon is identified as atmospheric turbulence which prompt undesired fluctuations of optical intensity at the receiver [7]. Consequently, the channel capacity is reduced, and bit error rate (BER) of transmission has increased [8].

Current FSO communication system is widely using single transceiver. Optimization of transmission quality with atmospheric turbulence is conducted by increasing laser power, selection of appropriate wavelength and implementation of optical lens [9]. Furthermore, multiple transmission point had been implemented for Ground-Satellite communication [10]. Moreover, as suggested in [11] CSK-OOK modulating process is reliable method conducting the investigation. As an alternative for overcoming atmospheric turbulence, this research paper proposes multiple transceiver system using laser diode with adder system to reduce the effect of atmospheric turbulence and increase the transmission performance of FSO communication.

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2. Design Methodology

2.1 Atmospheric Turbulence Modelling

In FSO communication, modulating light source is transmitted from transmitter channel to receiver channel [12]. Light intensity is attenuated due to non-ideal propagation of light and factors such as scattering, beam absorption, scintillation and beam wander over long transmission distance. As stated in [13], disturbance in FSO communication can result in low signal-to-noise ratio (SNR), high bit error ratio (BER) and loss of transmission.

The attenuation effect can be simulated by proposing atmospheric turbulence model. Black coloured solar tinted film with tested visibility of 30% is adopted to simulate intensity attenuation due to the atmospheric turbulence. It is commonly installed on windows to reduce emission of light and heat passing through the windows.

The refractive index of solar tinted film is not measured however it is measured in term of percentage of visibility. Two range of wavelength are measured such as visible light spectrum from 380nm to 780nm and infrared light spectrum from 900nm to 1000nm. The main factor for reducing light intensity is visible light attenuation while infrared rejection rate is used to determine attenuation of heat through the film. The characteristics of visible light rejection can be used as light filter in FSO communication to cause attenuation and fluctuations in light source.

In Fig. 1, visibility percentage of multiple layers of tinted films are measured. Measurement of attenuation is conducted by using transmission meter with low-power wide spectrum light source such as white LED. However, rejection rate of visible light measured may not be identical for laser beam as the light source is high-power focused spectrum at 650nm. The expected light attenuation will be lower as compared to measured visible light rejection rate. However, filter of stacked multiple layers can increase the rejection rate to cause intensity of laser beam attenuated significantly.

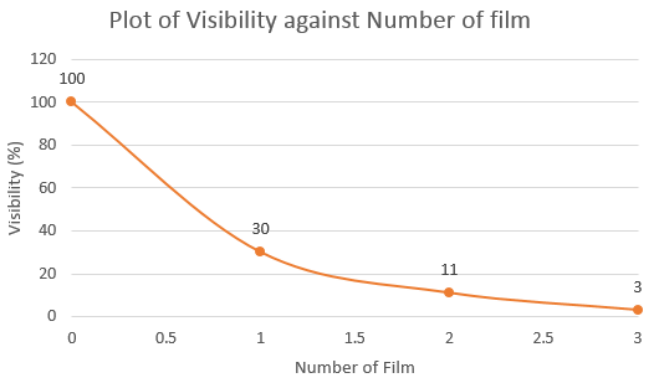

Fig. 1 - Measured visibility of a solar tinted film

In this system, the transmission channel is made up of three transceiver pairs, cable trunking as transmission path and mirrors as reflecting surface for doubling transmission distance. Three different situations of atmospheric turbulence are planned by placing the filter based on the design of prototype as seen Fig. 2.

- Point before reflection – T
- Point after reflection – R
- Point before and after reflection – TR

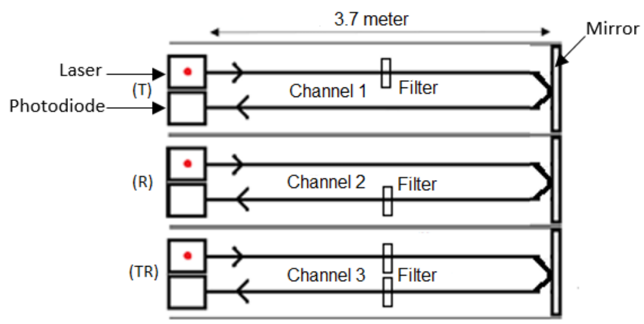

Fig. 2 - Definition of cases of T, R, and TR according to the placement of filter(s) along the laser transmission path

These three cases mentioned above will be tested individually to verify the performance of multiple transceiver system. Fig. 2 shows the plan of filter placement in the system. The filters are placed in channel 1 to channel 3 as shown in Fig.2 in the order of T, R and TR. Each case will be tested at once and the result will be categorized as case T, R, and TR.

Fig. 3 shows the amplitude of signal received at photodiode with filter placed in different cases. The received signal of case T and case R is small in variation with placement of 2 layers of filter. The performance of system in case T is slightly lower than case R due to the scattering at mirror surface. For case TR, beam attenuation up to 37% for the case of one layer of filter. It is obvious that the signal for the case TR is severely attenuated when two layers of filter is applied, while the cases of T and R indicate only 37% of attenuation. The attenuation patterns for all the cases of T, R, and TR are shown to be generally consistent with the number of filters applied, except for the case of TR where a slightly higher reading is observed for the filter of 3-layer as compared to 2-layer. This random fluctuation occurs because for the case of TR, the light beam will pass through the filter two times during the transmission and the scattering of the laser beam which could cause the fluctuation becomes more apparent when more layers of filter are applied. However, this random fluctuation can be reduced by repeating the measurement for the average value. With the defined cases of T, R, and TR, this approach of attenuation control is used to model the atmospheric turbulence in this investigation.

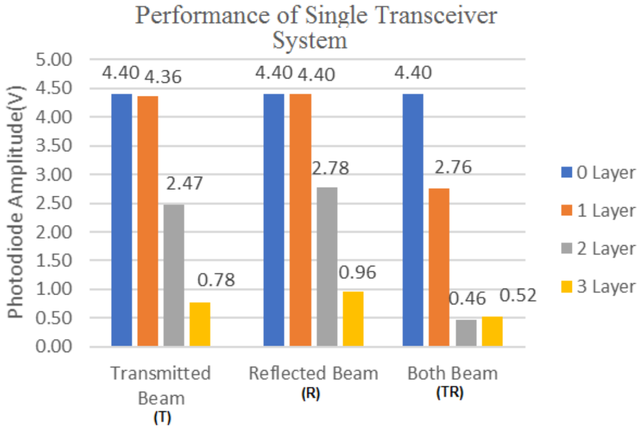

Fig. 3 - Attenuation effects according to the layer of filters applied for cases T, R, and TR in a single transceiver system

For the case of multiple transceiver system, the placement as well as the number of filters applied is randomized as shown in the Table 1 below. The randomization is set within two set possible combinations for the case of three transceiver system (referred as multiple transceivers in this work). The three channels are labelled as Ch1, Ch2, and Ch3. The relative attenuation level is indicated by the total filter(s) applied in each of the combinations. Both combinations are applied for each of the cases of T, R and TR of the multiple transceiver system proposed.

Table 1 - Combinations of filter for each attenuation level

Relative attenuation level	Combination 1 (layer)			Combination 2 (layer)		
	Ch1	Ch2	Ch3	Ch1	Ch2	Ch3
1	0	0	1	-	-	-
2	0	1	1	0	0	2
3	1	1	1	0	0	3
4	1	1	2	0	2	2
5	1	1	3	1	2	2
6	2	2	2	0	3	3
7	2	2	3	1	3	3
8	2	3	3	-	-	-
9	3	3	3	-	-	-

2.2 Multiple Transceiver System

The proposed multiple transceiver system consists of three identical channels of laser beam communication lines. The schematic of the whole system is shown in Fig. 2, where the totally length of the transmission for each channel is 7.4 meters, with mirror reflection at the point of 3.7 meters. Each channel is designed with an Arduino microcontroller as a transmitter and receiver, where the TX and RX pins are used to communicate. An Arduino laser module (KY-008) is used as a laser light emitter and a monolithic photodiode (OPT101) is used to detect the laser light sent. The summing amplifier and comparator used in this system are discussed separately below.

2.2.1 Summing Amplifier

Op-Amp OPA2137P is used to configure summing amplifier capable to output summation of all signal from photodiode. The connection of op amp is as shown in Fig. 4. Using this configuration, the summed signal will be used as input to RX pin receiver. To allow the Op-Amp to be working in intended function, the supply voltage need to be set at the range of 2 volts higher than peak output voltage to avoid voltage saturation [14]. However, due to supply voltage of 7.7V is used, peak output voltage will not be linear with directly summed output. The peak amplitude will be 6V as the output voltage is bounded by supply voltage and non-ideal Op-Amp.

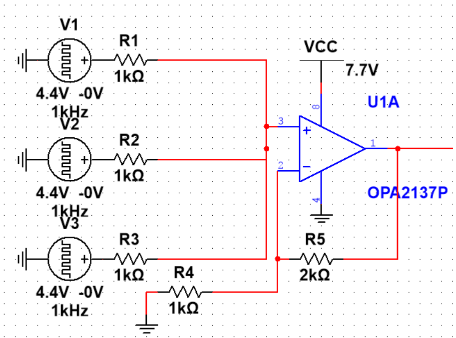

Fig. 4 - Op-Amp configuration for summing amplifier

2.2.2 Comparator

In FSO communication system, some noise may be introduced during the process of detection and amplification of signals and it causes unwanted distortion on the received signal [15]. Besides, the front end of optical detector is the weakest due to immense noise being picked up [16]. Hence, a comparator circuit with AD8561AR comparator and 10k Ohm potentiometer as illustrated in Fig. 5 is constructed to eliminate noise that is present in the received signals as well as reshaping the received signals as close to originally transmitted signal. Furthermore, the potentiometer is also used to set threshold [17] to amplify the operating range of Arduino due to input signal lower than reference voltage of Arduino. Therefore, the used of setting threshold enables signals with amplitude lower than Arduino reference voltage become high. The potentiometer is set at 23.6% to provide a 1.92V reference voltage into the comparator to mend the received signals with minor distortion become a smoothen signals as shown in Fig. 6.

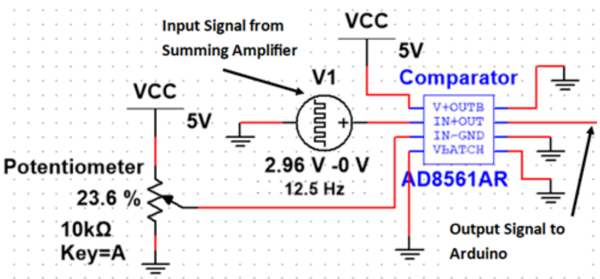

Fig. 5 – Comparator circuit

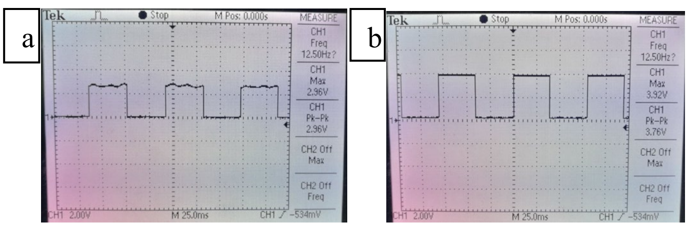

Fig. 6 - a) Distorted received signal; b) Smoothen received signal

3. Results and Discussions

The performance of the system can be based on several observations in term of summed output, comparator output, SNR, BER and success rate of communication.

3.1 Summation of Detected Signals

The output response at each relative attenuation level in case T is as shown in Fig. 7. Result of direct summed output and Multisim output are higher than the summing amplifier output. This is due to the amplifier is bounded by the supply voltage, hence higher supply voltage will produce output similar to direct summed output. For case T, the output from summing amplifier began to drop at attenuation level 5, dropped below threshold between level 7 and level 8 as observed in Fig. 8. The result is similar to reflected path case however the slope between level 7 and level 8 is steeper in this case. Based on the slope, it is clear that performance of all channels is well enough to survive up to high degree of atmospheric turbulence.

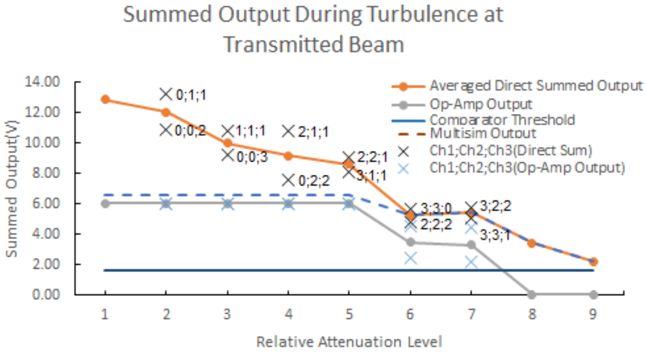

Fig. 7 - Summed output for case T

For case R, the output from amplifier began to drop at level 5 and dropped below threshold of comparator in between level 7 and level 8 as shown in Fig. 8. Therefore, the system will likely operate up to attenuation level of 7.5 during atmospheric turbulence at reflected path.

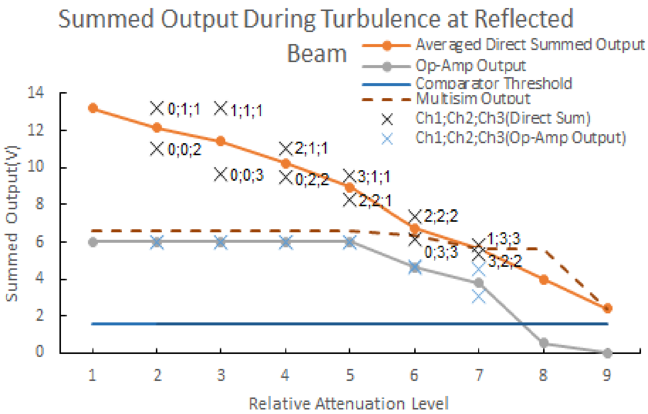

Fig. 8 - Summed output for case R

During atmospheric turbulence at both paths, the performance will drop dramatically due to the signals suffer attenuation of same degree twice. Based on Fig. 9, the output from summing amplifier began to drop at attenuation level 3 and drop below comparator threshold between level 6 and level 7. Fluctuation in summed value is found between level 4 to level 6. In other word, one of the attenuation level combination caused the output dropped below threshold. The combination causing the fluctuation is found to be 2;2;1. This is due to laser beam had been in two channels had been eliminated, remaining one with extremely low amplitude. Nevertheless, the signal was successfully summed, and the output curve is similar to direct summed output curve.

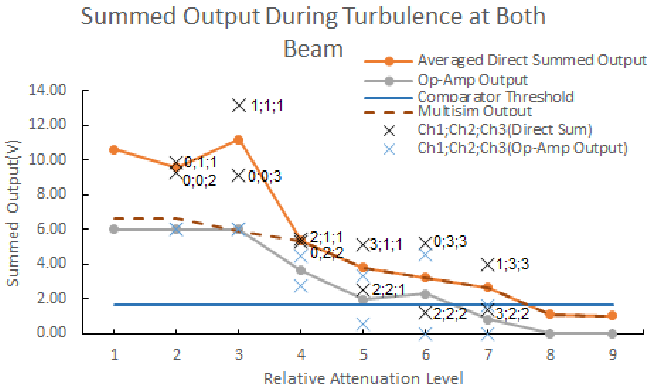

Fig. 9 - Summed output for case TR

After evaluating the summed outputs during three different location of atmospheric turbulence, the performance of multiple transmitting and receiving point can be observed based on the summed output. For instance, output voltage of 6V at summing amplifier output can guarantee 100% successful transmission. However, drop in summed output also means decrease in success rate of transmission. For case of atmospheric turbulence exist in transmitted path, 100% success rate is observed up to attenuation level 5, followed by atmospheric turbulence at reflected path which 100% success rate is up to attenuation level 6. Meanwhile the system can assure 100% success rate up to attenuation level 3 for atmospheric turbulence at both paths. The performance beyond these attenuation level will be discussed in other sections representing the success rate against attenuation level.

3.2 Signal-to-Noise Ratio (SNR) Analysis

SNR is a necessary parameter used to quantify the link performance of a laser-based FSO communication system. SNR is a ratio of detected signal strength over detected noise strength. Hence, the higher the value of SNR, the better the link performance of FSO communication system [18]. The analysis is conducted by using visibility level defined by number of filter films placed on transmission path.

As demonstrated in Fig. 10, drop in visibility level of transmission medium leads to decrease of SNR value, due to the attenuation of signal strength caused by the atmospheric turbulence. The SNR value for triple transceiver is higher than the double transceiver as well as single transceiver throughout different degree of atmospheric turbulence. Thus, the usage of multiple transceivers can improve the SNR when the visibility of transmission medium decreases.

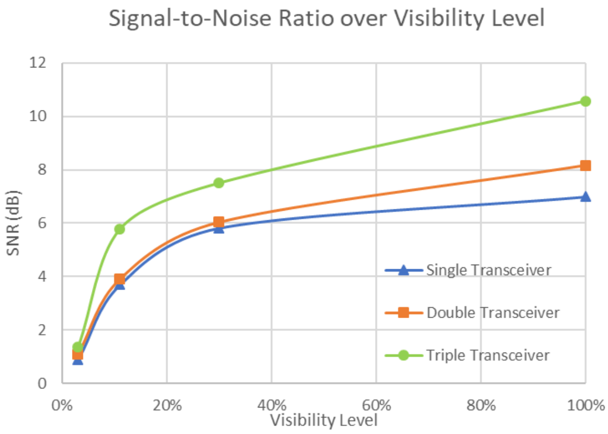

Fig. 10 - Signal-to-noise ratio versus visibility level of transmission medium

3.3 Bit Error Ratio (BER) Analysis

BER is another fundamental parameter to quantify the reliability of laser-based FSO communication link. BER is the number of error bits over number of transmitted bits. As illustrated in Fig. 11, the value of BER increases when the visibility of transmission medium decreases. A communication system with lower BER indicates that it poses better performance link [19].

Fig 11 shows the results of BER analysis taken for different scenario of transmission medium with visibility level such as 3%, 11%, 30% and 100%. The BER analysis is compared between single transceiver, double transceiver and triple transceiver. As found in Fig. 11, the laser-based FSO system with triple transceiver is identified to attain lower BER value when the visibility level is at 11% and 30%. Hence, it is concluded that FSO communication system with triple transceiver achieve a better performance link than FSO communication system with single or double transceiver.

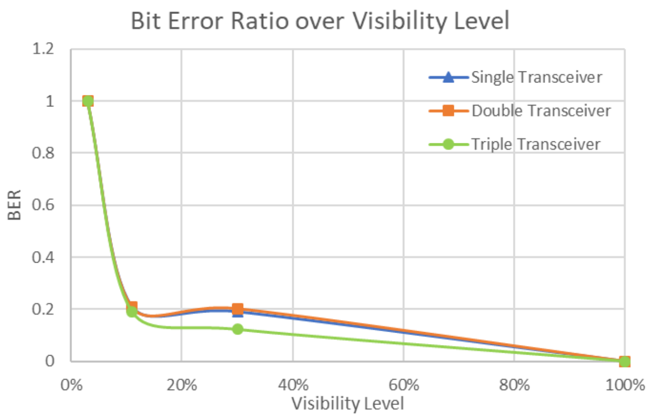

Fig. 11 - Bit error ratio versus visibility level of transmission medium

Fig. 12 indicates that as the relative attenuation level increases, the magnitude of SNR decreases. SNR of case R is the best among other cases where the slope is less steep than other cases. The SNR of case TR at attenuation level is observed at 6 while observation of 0 SNR for case T and R at attenuation level 7.

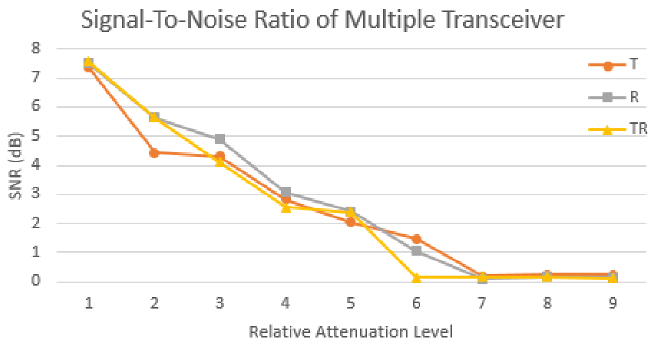

Fig. 12 - Signal-to-noise ratio over attenuation level under the meodeled turbulence

Fig. 13 shows the higher the attenuation level, the higher the BER will occur in the FSO communication system. In the worst case of attenuation level, the recorded BER is 1 due to total failure of receiving the message. Based on Fig. 13, the maximum acceptable magnitude of BER is 0.4 at attenuation level 5 for case TR and level 6 for cases T and R. The BER of case T and case R is 1 at attenuation level 7 while case TR is at 6. Hence, the system will have total failure at attenuation level 6 for case TR and level 7 for case T and case R.

Fig. 13 - Bit error ratio over attenuation level under the modeled turbulence

3.4 Success Rate

Fig. 14 illustrates the performance of multiple transceiver system in term of success rate. For case R, the performance of single transceiver channel can operate without fluctuation in success rate is up to relative attenuation level 3. However, multiple transceiver system can operate up to attenuation level 6 without fluctuation. For case T, single transceiver system can operate without fluctuation up to attenuation level 3 and multiple transceiver system can operate up to attenuation level 5. Case TR performed the worst among all other cases. For single transceiver system, the system can operate until attenuation level of 2. Meanwhile, multiple transceiver system can operate up to attenuation level 4 during the worst turbulence.

Based on the performance observed in Fig. 14, the improvement factor of multiple transceiver system can be determined. Improvement factor is the measurement of improvement in multiple transceiver system over single transceiver system.

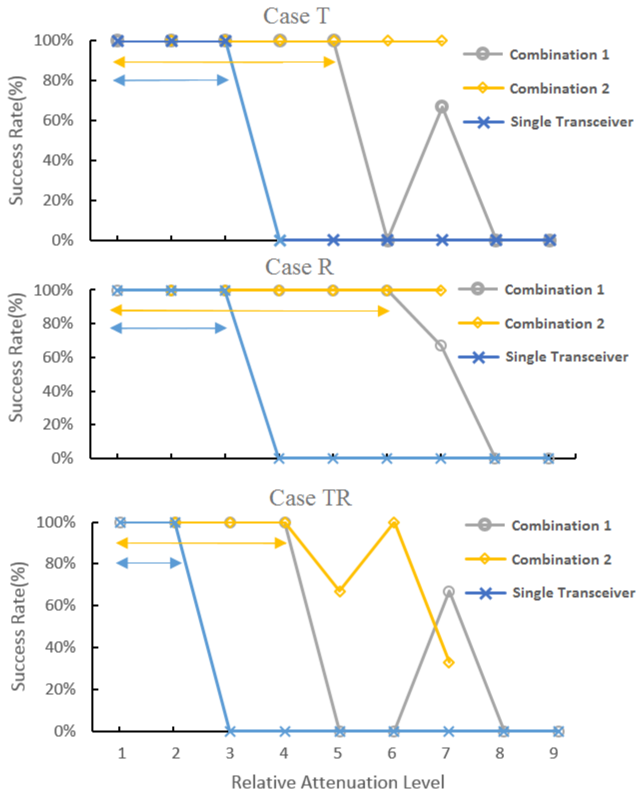

Fig. 14 - Success rate of transmission over relative attenuation level bit

Table 2 shows the performance comparison as well as the improvement factors for all the cases of T, R, and TR between the single transceiver and multiple transceiver systems. Conclusively, the multiple transceiver system is improved at least by a factor of 1.7 times.

Table 2 - Improvement factor of multiple transceiver system

Case	Attenuation level with 100% Success Rate		Improvement Factor
	Single Transceiver	Multiple Transceiver	
T	3	5	1.7
R	3	6	2.0
TR	2	4	2.0

4. Conclusion

The working principle of the proposed multiple transceiver system is demonstrated. The performance of the proposed system is evaluated based on the measurements of SNR, BER, and the success rate of transmission, with the intensity turbulence modeled. Comparisons on these measurements indicate that the proposed system is more stable than the single channel communication system. On average, the proposed system results an improvement by a factor of two. Hence, the multiple transceiver system can be used to minimize the issue of signal instability or signal lost due to the atmospheric turbulence.

5. Acknowledgement

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