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# Multi-channel Optical Wireless Communication under the Effect of Low Electric Field

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## ABSTRACT

In this study, the multiple-input multiple-output (MIMO) technique is proposed to mitigate the influence of an external electric field on the free space optical (FSO) communication. The main advantages of the proposed technique are: decrease the attenuation (decrease bit error rate BER), improve data transmission at all divergence angles, and increase the quality (Q-factor) (even when it decreases at higher divergence angles). The importance of these results can be used to solve the problem of electric discharges that occurs on power transmission lines that interfere with the optical wireless system.

**KEYWORDS**: Free Space Optics; electric fields effect; multi-channels.

**الخلاصة**

في هذه الدراسة ، تم اقتراح تقنية مداخل-متعددة ومخارج-متعددة (MIMO) للتخفيف من تأثير المجال الكهربائي الخارجي على اتصالات الفضاء الحر البصرية (FSO). من المزايا الرئيسية للتقنية المقترحة هي: تقليل التوهين (تقليل نسبة الخطأ BER) ، تحسين نقل البيانات في جميع حزم الارسال وزيادة عامل Q (حتى عندما ينخفض عند حزم الارسال الاعلى). أهمية هذه النتائج ، في امكانية استخدامها لحل مشكلة التفريغ الكهربائي الذي يحدث على خطوط نقل الطاقة التي تتداخل مع النظام اللاسلكي البصري.

## INTRODUCTION

In free-space optical (FSO) communication, the transmitted light responds to the influence of perturbations in their surroundings. An FSO technique has been developed for transmitting and receiving signals without significant loss [1]. FSO transceivers are designed to provide high-speed, free licensed, and secured communication system [2]. FSO channels play a significant role in the transport of the high-data rate over long distances without exhausting RF resources [3]. Several challenges facing the communication systems lead to loss of the line of sight (LOS) due to Scatter of the light photons such as natural atmospheric effects; (aerosol, smoke, fog, and rain) [4-7] and artificial effects; (magnetic and electric fields) [8, 9]. Therefore, the operation parameters of the FSO communications system can be modified depending on the surrounding conditions. Different methods used to enhance the transmission rate of FSO systems, different

techniques have been suggested for example; transmitting multiple independent data channels via employing wavelength division multiplexing (WDM) [10] and orbital angular momentum (OAM) multiplexing [11], single-input multiple-output (SIMO) [12] and multiple-input multiple-output (MIMO) system channels [13]. MIMO-FSO communications techniques were mostly investigated for providing spatial diversity to deal with atmospheric turbulence [14–16]. In this paper, the MIMO technique is used to improve the performance of the FSO system under the influence of an external electric field on the axis of propagation light by using simulation software OptiSystem7.0 (Optiwave Systems Inc).

## EXPERIMENTAL AND SIMULATION WORK

An experimental setup is designed to evaluate the effect of an external electric field on the optical wireless signal as shown in Figure 1. It is done by using a diode laser source (5mW, 650 nm), DC Power Supply, optical power meter, square conductor loop for force and current measurement. The transmitted signal is influenced by the electric field (E) that is generated around the conductor loop when a current I (A) move in the conductor.

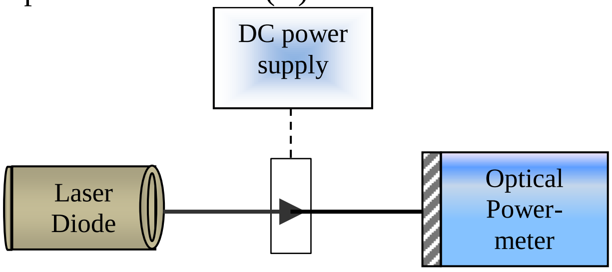


**Figure 1.** Block diagram of an external electric field on the optical wireless signal.

Simulation of FSO links by using the MIMO technique has been designed to analyze and improve the performance of the FSO system under the effect of the low electric field as shown in Figure 2. It consists of four channels (4T /4 R), fork to duplicate the input beam into all power-meter (to calculate the BER value, the signal quality (Q-factor) and display eye diagram), Pseudo-channels, combiner to link all receivers with both bit error rate (BER) analyzer and optical Random Bit Generator, NRZ Pulse Generator, Mach-Zehnder Modulator, avalanche photo-detector (APD). In addition, the effect of the electric field is added through the noise source generator. The proposed FSO employed parameters has given in Table 1.

**Table 1.** system simulation parameters [8].

| Parameter | Value |
|---|---|
| Laser wavelength (nm) | 1550 |
| Attenuation | 25 |
| Transmitter optical power (mW) | 20 |
| Receiver sensitivity (dBm) | -20 |
| Receiver diameter (cm) | 20 |
| Transmitter efficiency | 0.5 |
| Receiver efficiency | 0.5 |
| Transmitter aperture(cm) | 2 |

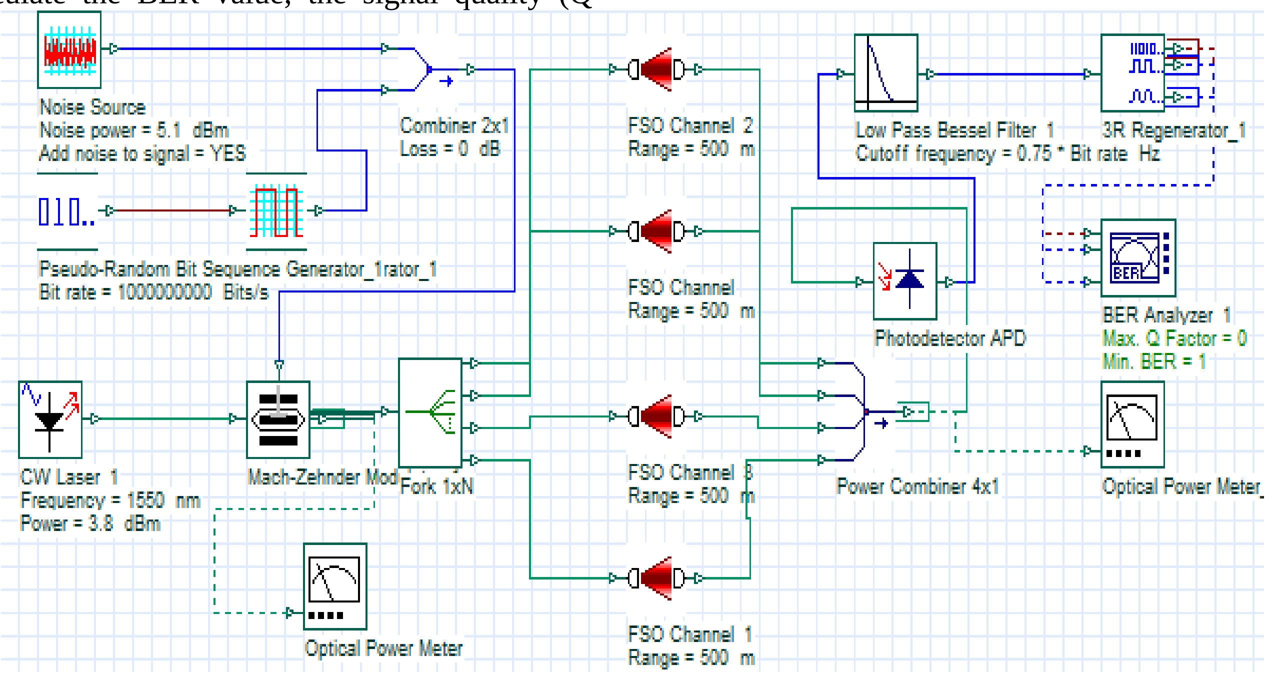


**Figure 2.** Simulation layout of MIMO-FSO.

## RESULTS AND DISCUSSION

The experimental results are illustrated in Table 2, they show the fluctuation in the output power as a function of the current (electric field). The current increases from (2 to 20 A) with step (2 A). The output power fluctuation results from adding noise through an external electric field. Table 2 illustrates the fluctuation of (Pout) as well as the generated noise due to an external electric field that was calculated experimentally. They demonstrate a serious noise effect (attenuation) on the main signal.

Simulations of (4Tx/4Rx) FSO systems are analyzed in three divergence angles 1, 2, and 3 mrad for different noise values. The recorded results have shown in Tables 3, 4, and 5. From these tables, it can be observed that the FSO system performance at works properly for all divergence angles 1, 2, and 3 mrad as Q-Factor ≥ 6, depending on [17]. Moreover, the Q-factor has reverse relation with the divergence angle values. Eye diagrams were used for verifying the recorded results, to estimate the output signals quality. The eye is fully opened at the lowest divergence angle then gradually turns to be opened partially at the midst

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2 mrad and highest 3 mrad divergence angles, as shown in Figures.3, 4 and 5.

**Table 2.** Experimental results of the output power fluctuation.

| I (A) | $P_{out}$ (mW) | Noise (mW) | $P_{out}$ (mW) |
|---|---|---|---|
| 0 | 0.94 | 0 | 1 |
| 2 | 0.978 | 0.038 | 1.04 |
| 4 | 0.992 | 0.052 | 1.055 |
| 6 | 1.027 | 0.087 | 1.092 |
| 8 | 1.307 | 0.367 | 1.4 |
| 10 | 1.51 | 0.57 | 1.6 |
| 12 | 1.88 | 0.94 | 2 |
| 14 | 2.2 | 1.26 | 2.34 |
| 16 | 2.55 | 1.61 | 2.7 |
| 18 | 2.8 | 1.86 | 2.98 |
| 20 | 3.12 | 2.18 | 3.6 |

**Table 3.** Simulation results for MIMO-FSO of 1mrad transmitter divergence angle.

| Pout (dBm) | Noise (dBm) | Q-factor | BER |
|---|---|---|---|
| 3.76 | 0 | | |
| 3.91 | 0.15 | 28 | $3.0e^{-173}$ |
| 3.96 | 0.35 | 27.8 | $9.1e^{-172}$ |
| 4.1 | 1.47 | 27.1 | $8.3e^{-163}$ |
| 5.26 | 2.3 | 26.5 | $4.4e^{-156}$ |
| 6.01 | 3.75 | 25.1 | $1.5e^{-140}$ |
| 7.52 | 5.1 | 23.9 | $6.3e^{-127}$ |
| 8.8 | 6.5 | 22.4 | $2.7e^{-112}$ |
| 10.15 | 7.5 | 21.3 | $1.3e^{-101}$ |
| 11.22 | 9.7 | 18.7 | $7.4e^{-079}$ |
| 13.5 | 11 | 17.1 | $2.2e^{-066}$ |

**Table 4.** Simulation results for MIMO-FSO of 2mrad transmitter divergence angle.

| Pout (dBm) | Noise (dBm) | Q-factor | BER |
|---|---|---|---|
| 3.76 | 0 | | |
| 3.91 | 0.15 | 14.9 | 1.6e-050 |
| 3.96 | 0.35 | 14.8 | 3.6e-050 |
| 4.1 | 1.47 | 14.4 | 4.5e-048 |
| 5.26 | 2.3 | 14.2 | 1.8e-046 |
| 6.01 | 3.75 | 13.6 | 9e-043 |
| 7.52 | 5.1 | 13 | 1.6e-039 |
| 8.8 | 6.5 | 12.4 | 5.8e-036 |
| 10.15 | 7.5 | 11.9 | 2.6e-033 |
| 11.22 | 9.7 | 10.7 | 2e-027 |
| 13.5 | 11 | 10 | 5e-024 |

**Table 5.** Simulation results for MIMO-FSO of 3mrad transmitter divergence angle.

| Pout (dBm) | Noise (dBm) | Q-factor | BER |
|---|---|---|---|
| 3.76 | 0 | | |
| 3.91 | 0.15 | 10.11 | $1.1e^{-024}$ |
| 3.96 | 0.35 | 10.1 | $1.7e^{-024}$ |
| 4.1 | 1.47 | 9.88 | $1.5e^{-023}$ |
| 5.26 | 2.3 | 9.7 | $8.2e^{-023}$ |
| 6.01 | 3.75 | 9.4 | $1.7e^{-021}$ |
| 7.52 | 5.1 | 9 | $4.4e^{-020}$ |
| 8.8 | 6.5 | 8.6 | $1.6e^{-018}$ |
| 10.15 | 7.5 | 8.3 | $2.3e^{-017}$ |
| 11.22 | 9.7 | 7.6 | $9e^{-015}$ |
| 13.5 | 11 | 7 | $3e^{-013}$ |

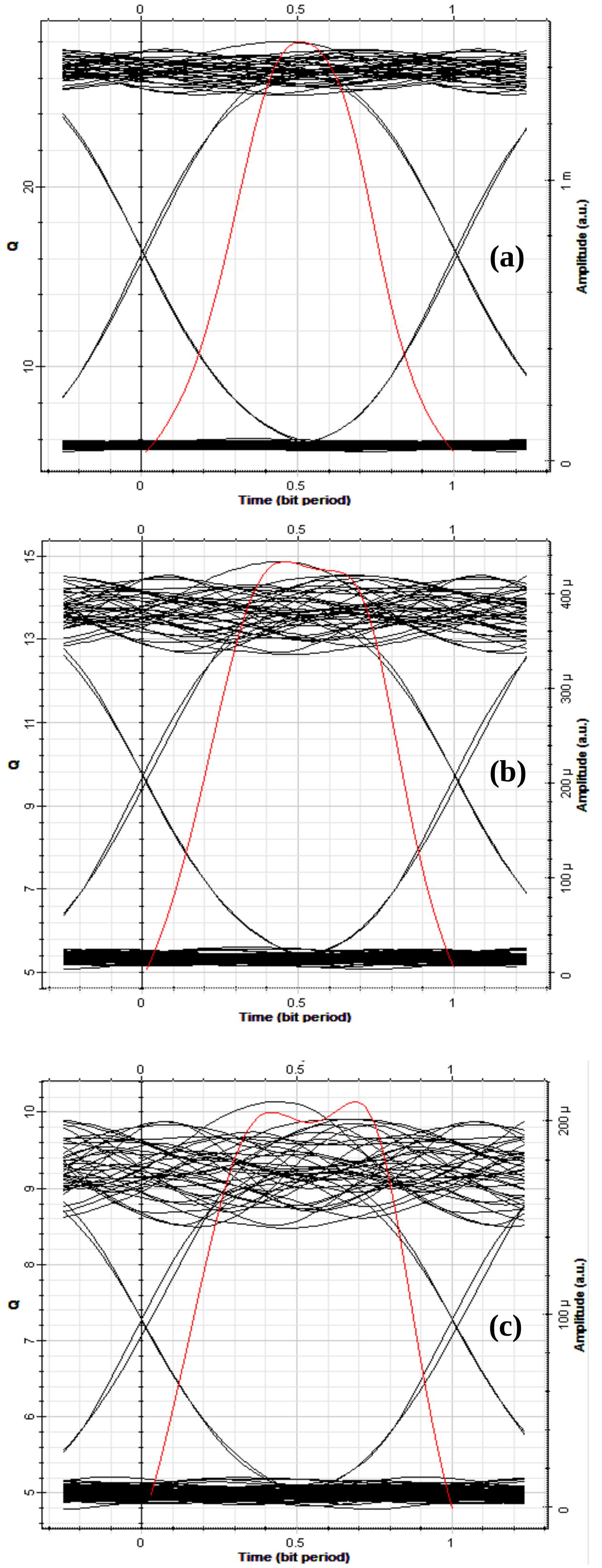


**Figure 3.** Eye diagram performance for MIMO-FSO at a) 1 mrad, b) 2 mrad and c) 3 mrad; with lowest noise (0.15) dBm.

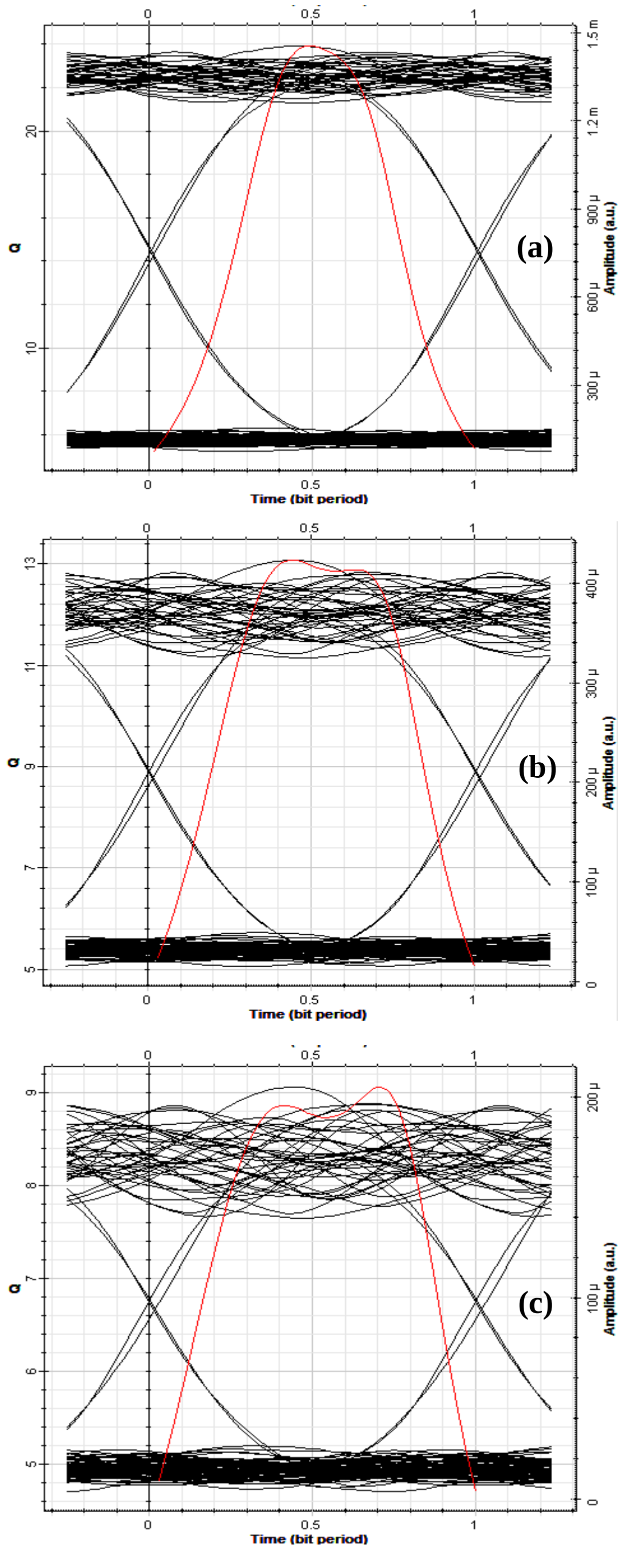


**Figure 4.** Eye diagram performance for MIMO-FSO at a) 1 mrad, b) 2 mrad and c) 3 mrad; at mid-point noise (5.1) dBm.

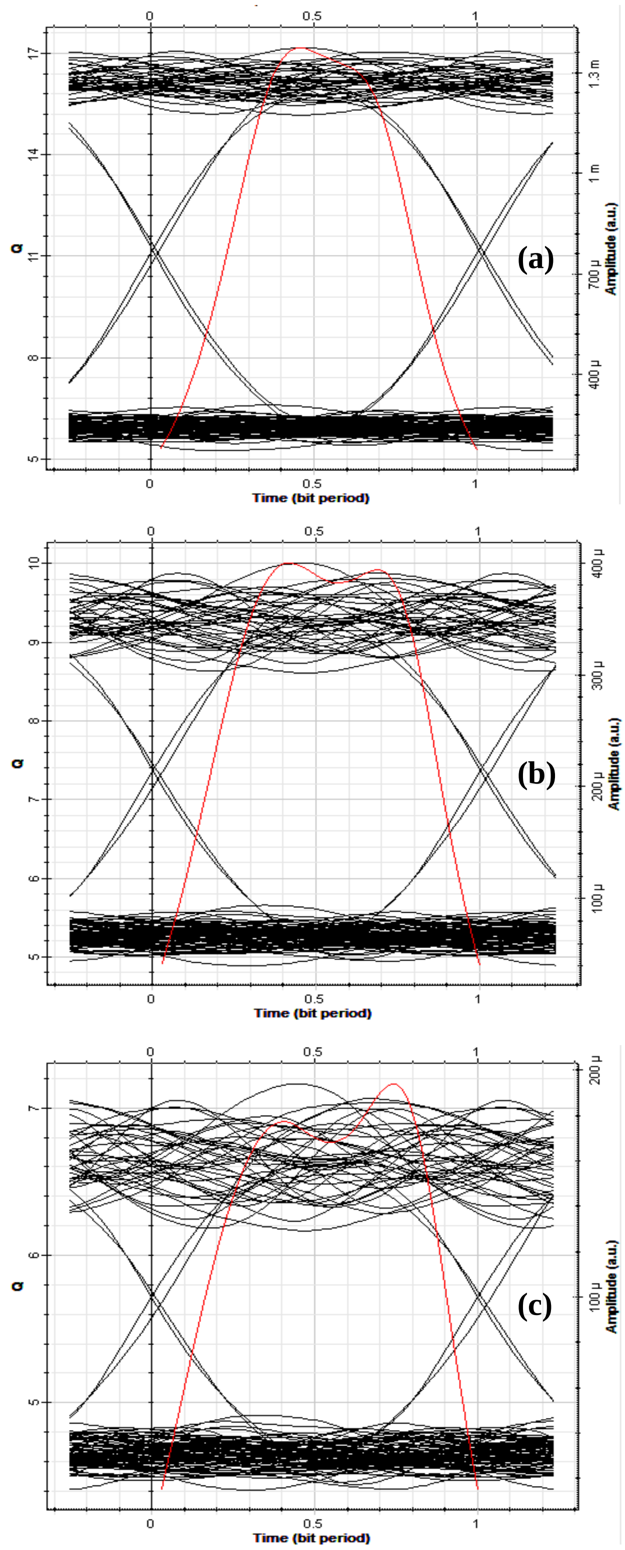


**Figure 5.** Eye diagram performance for MIMO-FSO at a) 1 mrad, b) 2 mrad and c) 3 mrad; with the highest noise (11) dBm.

## CONCLUSIONS

An external electric field can influence the optical wireless system over a clear atmosphere and induce bit error. The MIMO technique is proposed to mitigate the influence of an external electric field on the FSO data transmission. The main advantages of the proposed technique are: decrease the attenuation (decrease BER), improve data transmission at all divergence angles, and increase the Q-factor (even when it decreases at higher divergence angles). The importance of these results can be used to solve the problem of electric discharges that occurs on power transmission lines that interfere with the optical wireless system.

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