Major Project Report
On

Performance analysis of a MIMO-Visible Light Communication system under the influence of ambient light

Submitted in partial fulfillment of the requirements of the subject

Project Work
EC107501EC

Submitted by

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Certificate

This is to certify that this is a bonafide record of the project presented by **Rangabhalta Sriteja**, roll number **20116084** during Winter, 2023 here in partial fulfilment of the requirements of the course Project Work (EC107501EC) in seventh semester of Bachelor of Technology in Electronics and Communication Engineering.

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Certificate by the Examiner

This is to certify that the Project Work entitled "Performance analysis of a MIMO Visible Light Communication system under the influence of ambient light" this is a bonafide record of the project presented by **Rangabhalta Sriteja**, roll number **20116084** during Winter, 2023 here in partial fulfilment of the requirements of the course Project Work (EC107501EC) in seventh semester of Bachelor of Technology in Electronics and Communication Engineering.

Examiner 1	**Examiner 2**
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Declaration

This is to certify that

1. The work comprised in this report is original and is done by myself under the supervision of my supervisor.

2. The work has not been submitted to any degree or diploma.

3. I have followed the guidelines provided by the institute in writing this report.

4. Whenever I have used materials (data, theoretical analysis and text) from other sources, I have given due credit to them in the text of the report and giving their details in the references.

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Rangabhatla Sriteja
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Abstract

This study compares Single Input, Single Output (SISO) and Multiple Input, Multiple Output (MIMO) systems using Non-Return to Zero (NRZ), Return to Zero (RZ), and Quadrature Phase Shift Keying (QPSK) modulations. The focus is on their performance in transmitting over distances and resilience to ambient light interference.

MIMO systems consistently outperform SISO in distance coverage, with NRZ and QPSK proving superior modulation choices. Ambient light resilience is a notable strength of MIMO, making it more robust in challenging lighting conditions. NRZ and QPSK also excel in mitigating interference from ambient light, further emphasizing their effectiveness. These findings provide crucial insights for designing communication systems tailored to specific performance requirements in diverse scenarios.

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Chapter 1

Introduction

The evolution of generations in communication technologies has been marked by significant advancements, with each generation building upon the limitations and capabilities of its predecessor. The transition from traditional wired communication to optical communication represents a crucial phase in this evolution.

Analog voice communication is the first generation communication with limited capacity and distance. In the second generation digital voice communication is introduced. It is achieved through technologies like GSM. There is an improvement in voice quality and data services are introduced, yet it is primarily designed for voice services only. Mobile broadband is introduced in the third generation, in which multimedia services, support for video streaming started and marked the beginning of mobile internet services. In the fourth generation Long-Term Evolution (LTE) is introduced for faster mobile data.

But there is a constant increase in number of devices and demand for more bandwidth, coverage etc. Now, with introduction of Internet of Things (IoT), streaming services there is a need of new and efficient generation of communication systems. Hence, the genesis of fifth generation of communication, where advanced wireless technologies, with higher frequencies and more efficient use of the spectrum are used. Optical communication which uses light in transmission offers increased data rates, longer transmission distances, and improved reliability. These factors made optical communication as a solution for high-capacity, long-distance data transmission. Therefore it emerged as a critical component of the internet backbone and data center infrastructure.

1.1 Visible Light Communication

Optical communication system can be defined as a communication system in which light is used carrier signal to transmit data as shown in figure 1.3. Here on, optical communication system refers to the model shown in figure 1.1 only. If the light used as carrier signal, falls in the visible light region, 400nm - 700nm or 430THz - 750THz of the electromagnetic spectrum, then such communication system is called Visible Light Communication (VLC). It can be both, wired or wireless. Figure 1.4 depicts block diagram of typical optical communication system. Optisystem software is used to realise the block diagram into circuits and study on.

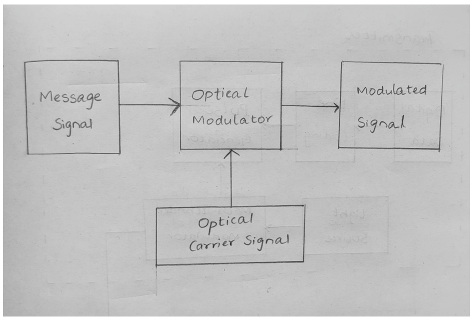

Figure 1.1: Light is used as carrier signal

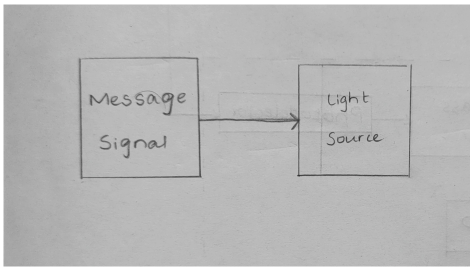

Figure 1.2: Light is transmitted directly

Figure 1.3: Two different kinds of Optical Communication.

Some of the advantages of visible light communication are it supports high data rates, uses abundant free spectrum, immune to electromagnetic interference. But, it distance limited, susceptible to blockages, interference due sunlight and ambient light, tapping wireless networks are easy, as it is wireless transmission fading is inevitable. There are many ways to mitigate these disadvantages like proper planning to install devices overcomes the distance and blockages problems. adopting better encryption techniques to increase privacy.

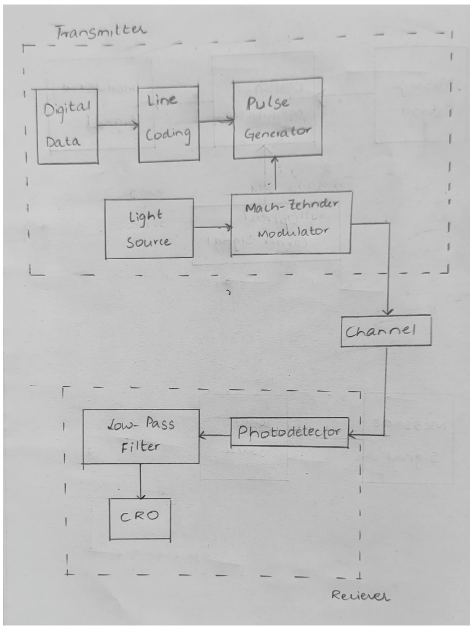

Figure 1.4: A typical optical communication system

1.2 Problem Definition

Study and analyse performance of a SISO and MIMO systems under the influence of ambient light with different line coding techniques. Here Bit Error Rate BER and received power are taken as parameter for comparison.

1.3 Software Used

OptiSystem is a comprehensive software tool for the design, simulation, and analysis of optical communication systems. Developed by Optiwave, OptiSystem provides a powerful platform for engineers, researchers, and designers working in the field of optical communication to model and simulate various components and systems.

1.4 Motivation

Visible light communication faces two problems by default, fading due to wireless transmission and interference due to ambient light. Overcoming these issues would resolve basic problem of VLC and help developing better systems.

1.5 Report Contribution

- Novel contributions in this report is studying a MIMO link under the influence of ambient light.
- Comparative analysis of SISO-VLC and MIMO-VLC under the influence of ambient light with different line coding techniques is done.

1.6 Report Organisation

- In Chapter 2, Spatial Diversity and various techniques involved in it are discussed. Then Spatial Multiplexing along with its key features are studied. Later, a Single-Input Single-Output (SISO) and Multiple-Input Multiple-Output (MIMO) system is designed and implemented in Optisystem v21.0. Their performance analysis is done with different line coding techniques.
- In Chapter 3 interference due to ambient light is studied. Later, a Single-Input Single-Output (SISO) and Multiple-Input Multiple-Output (MIMO) system is designed and implemented in Optisystem v21.0. Their performance analysis is done with different line coding techniques.
- In Chapter 4, drawbacks of the circuits made is discussed along with some idea that can be implemented for further development of the communication systems.
- In Chapter 5 report is concluded with some observations and inferences.
- In Chapter 6 all the publications referred to are placed here.

Chapter 2

Spatial Diversity

In wireless communication systems where the signal may experience fading and other impairments as it travels through the environment. Spatial diversity is a technique used to improve signal reliability and mitigate the effects of fading and interference. It involves using multiple spatially separated antennas for transmission and/or reception. The basic idea is to take advantage of the spatial variations in the received signals to enhance the overall system performance.

Spatial Diversity can be achieved by adopting various techniques and few are as follows:

1. Single antenna multipath program: Here, single antenna transmits signal into multiple possible paths which faces different fading conditions thus diversifies signals are captured by single antenna at the receiver end.

2. Receive Diversity (Selection Diversity): Use multiple receive antennas, and choose the signal from the antenna with the highest quality. This is a basic form of spatial diversity without explicitly using multiple transmit antennas.

3. Maximal Ratio Combining (MRC): Combine signals from multiple receive antennas with different weights, giving more weight to signals with better quality. This technique enhances the overall received signal quality.

4. Receive Diversity: Use multiple receive antennas, and employ techniques such as maximal ratio combining (MRC) or selection diversity to combine signals received from different spatial paths.

5. Spatial Multiplexing: Transmit multiple independent data streams simultaneously using multiple antennas at the transmitter and receiver. This technique enhances data throughput and takes advantage of spatial variations.

2.1 Spatial Multiplexing

Spatial multiplexing is used in multiple-input, multiple-output (MIMO) communication systems to transmit multiple independent data streams simultaneously over the same frequency channel. It takes advantage of the spatial dimensions created by multiple antennas at both the transmitter and receiver to enhance the overall data throughput.

Key features of Spatial Multiplexing are:

1. Multiple Antennas: Spatial multiplexing requires the use of multiple antennas at both the transmitter and receiver. These antennas are often arranged in arrays.

2. Independent Data Streams: The data streams transmitted by each antenna are independent of each other. This independence allows multiple pieces of information to be sent simultaneously.

3. Spatial Channels: Each antenna creates a spatial channel through which a separate data stream can be transmitted. The spatial channels experience different fading characteristics due to variations in the propagation environment.

4. Receiver Processing: At the receiver, the signals received from different antennas are processed separately. The goal is to separate the independent data streams that were transmitted simultaneously.

5. Spatial Multiplexing Gain: Spatial multiplexing provides a multiplexing gain, which increases the data rate without requiring additional bandwidth. The multiplexing gain is related to the number of spatial channels and the independence of the transmitted data streams.

6. Capacity Improvement: Spatial multiplexing increases the overall capacity of the communication channel by transmitting multiple data streams concurrently. This is particularly beneficial in environments with rich multipath propagation.

2.2 Circuit Design

2.2.1 Block Diagram

These characteristics of MIMO communication system more efficient than a SISO communication system. A typical SISO and MIMO systems are shown in figures 2.1, 2.2 respectively, where the transmitter and receiver blocks are similar to the one shown in figure 1.4.

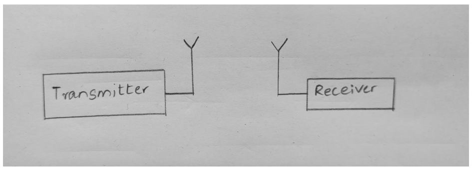

Figure 2.1: SISO wireless communication system

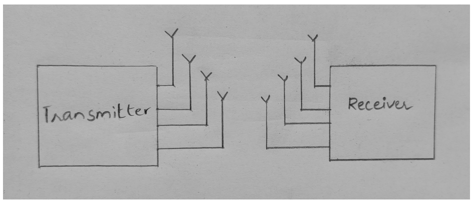

Figure 2.2: MIMO wireless communication system

2.2.2 Optisystem

In Optisystem, the above block diagrams are implemented as the following circuits in which figure 2.3, 2.4, **??** depicts SISO systems with Non-Return-to-Zero (NRZ), Return-to-Zero (RZ), Quadrature Phase-Shift Keying (QPSK) line coding techniques respectively.

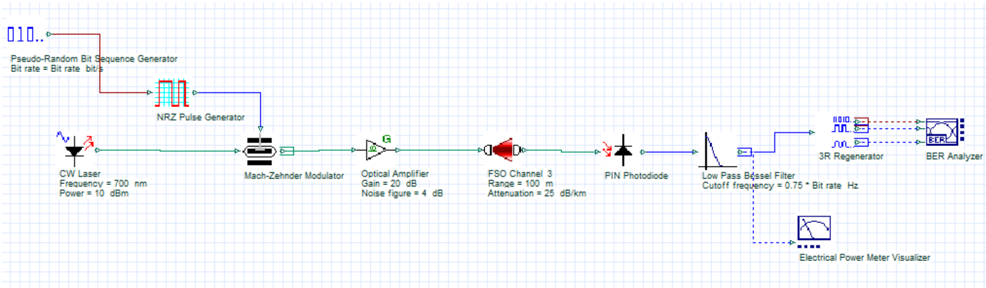

Figure 2.3: SISO NRZ system

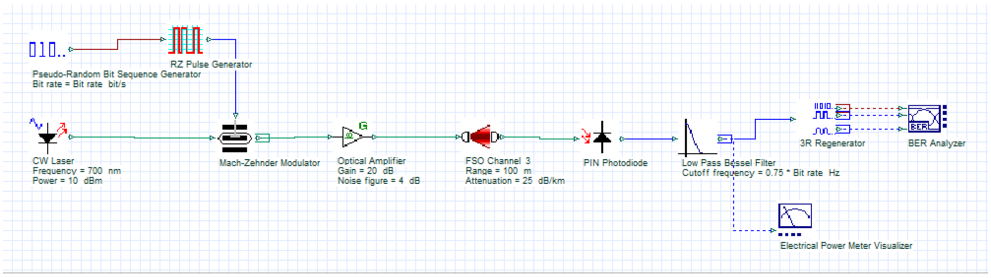

Figure 2.4: SISO RZ system

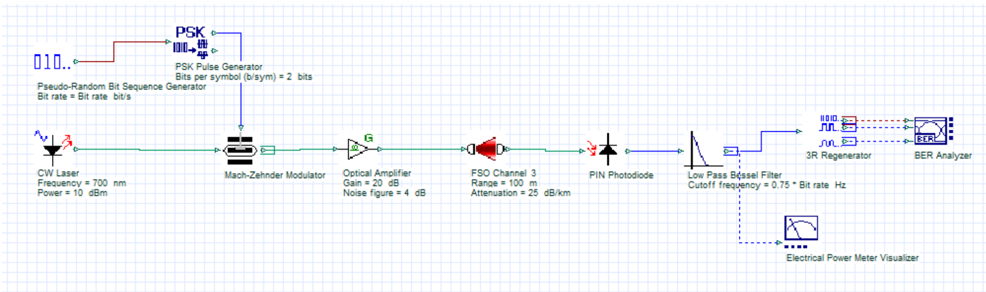

Figure 2.5: SISO QPSK system

Similarly, figure 2.6, 2.7, **??** depicts MIMO systems with NRZ, RZ, QPSK line coding techniques respectively.

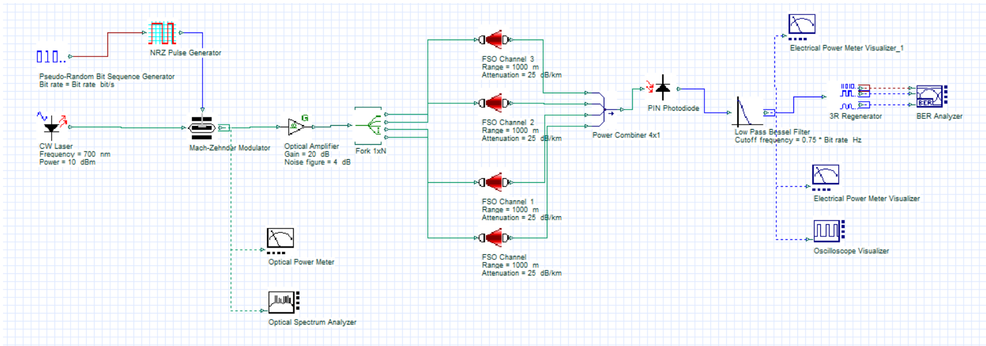

Figure 2.6: MIMO-NRZ system

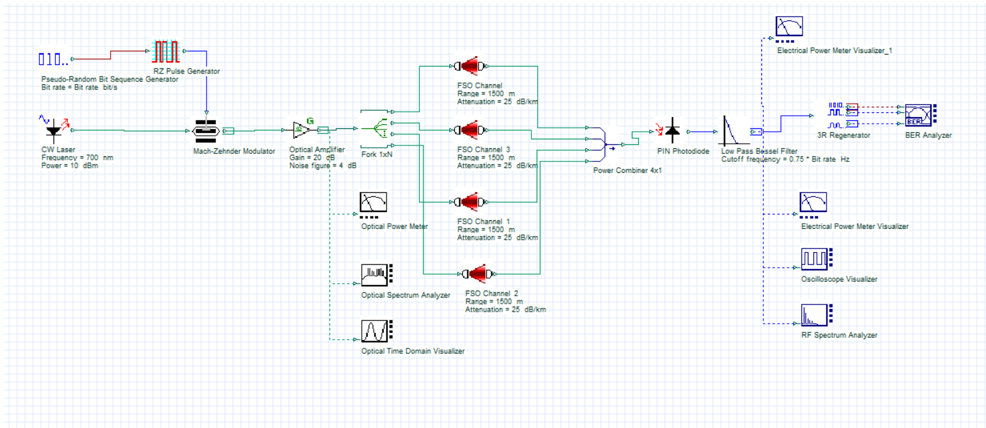

Figure 2.7: MIMO-RZ system

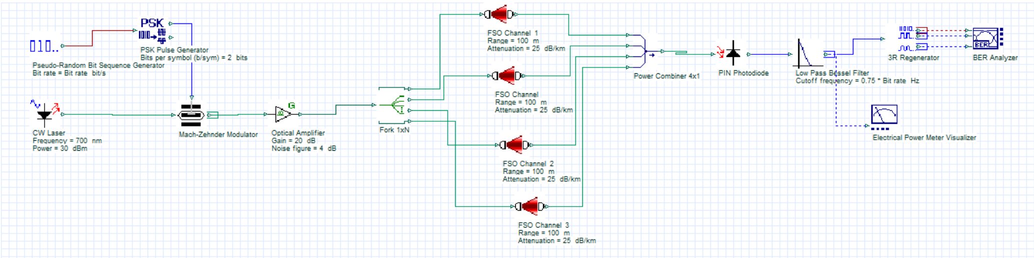

Figure 2.8: MIMO-QPSK system

2.3 Performance Analysis

Bit Error Rate and Q-factor are two metrics indicates the quality of a communication link. BER is defined as number of erroneous bits per total number of bits transmitted. Similarly, Q-factor represents the difference between the average energy of correctly received bits and the average energy of incorrectly received bits, normalized by the standard deviation of the received signal. The relationship between Q-factor and BER is inversely proportional: as the Q-factor increases, the BER decreases. Therefore, Q-factor must be high and BER must be low.

To compare the performance of each system, Bit Error Rate BER, received power and Q-factor are takes as metrics with following parameters:

Parameters	Values/ Range
Datarate	1 Gbps
Power of LASER	30dBm
Wavelength of LASER	700nm
Gain of optical amplifier	20dB
Noise figure of optical amplifier	4dB
Channel attenuation	25dB/km

Table 2.1: Parameters table

Observed values are plotted between distance and log10(BER), received power and Q-factor.

From figure 2.9 and 2.10, RZ line coding techniques reaches maximum BER value allowed with in less distance. Hence it is has the least performance index, whereas NRZ and QPSK performs almost close to each other.

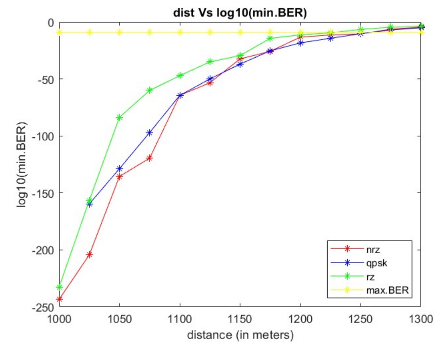

Figure 2.9: BER comparison in SISO system

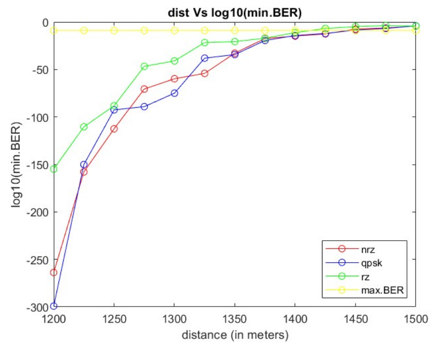

Figure 2.10: BER comparison in MIMO system

Figure 2.11: BER comparison in SISO and MIMO systems

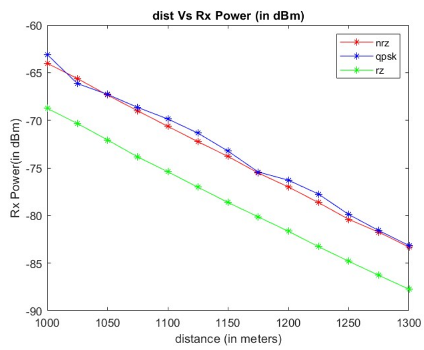

Figure 2.12: Received power comparison in SISO system

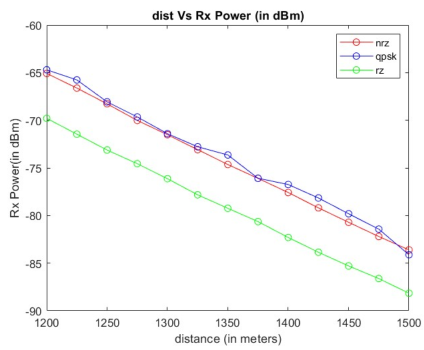

Figure 2.13: Received power comparison in MIMO system

Figure 2.14: Received power comparison in SISO and MIMO systems

From figure 2.12 and 2.13, with RZ line coding techniques power is received very less than the others. Hence it is has the least performance index, whereas NRZ and QPSK performs almost close to each other, but mostly QPSK outperforms NRZ here.

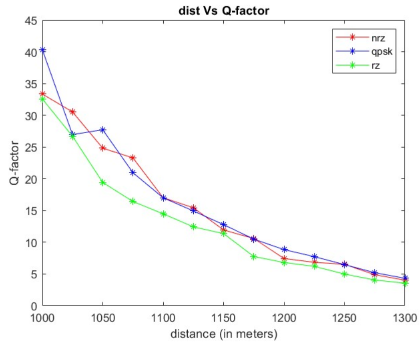

Figure 2.15: Q-factor comparison in SISO system

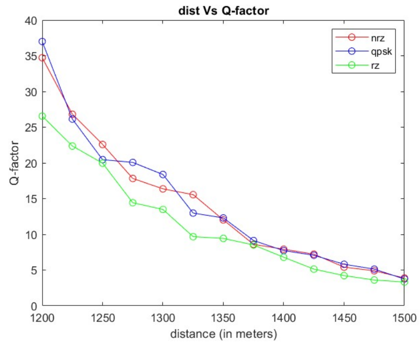

Figure 2.16: Q-factor comparison in MIMO system

Figure 2.17: Q-factor comparison in SISO and MIMO systems

Similarly, from the figures 2.15 and 2.16, Q-factor is least for RZ but QPSK and NRZ performs almost similar.

From the figure 2.9 and 2.10, there is a limit to the link distance is observed. After the limit BER is greater than 1/datarate, which is not acceptable.

Line Coding	Achievable Link Distance
NRZ	>1250m
QPSK	>1250m
RZ	<1250m

Table 2.2: Achievable Link Distance in SISO Systems

Line Coding	Achievable Link Distance
NRZ	nearly 1450m
QPSK	nearly 1425m
RZ	nearly 1425m

Table 2.3: Achievable Link Distance in MIMO Systems

As shown in the above tables 2.2 and 2.3, MIMO achieves longer distance than SISO system.

The three figure 2.18, 2.19, 2.20 depicts the combined comparison between SISO and MIMO systems with different line coding techniques and can observe that long distance is achieved in MIMO systems by NRZ and QPSK. RZ performs least in both systems.

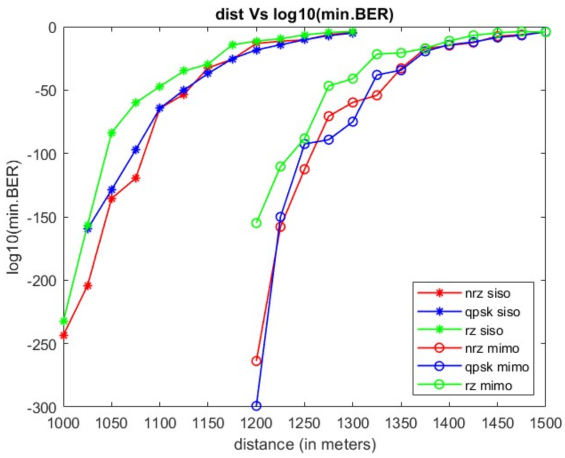

Figure 2.18: SISO VS MIMO with respect to BER

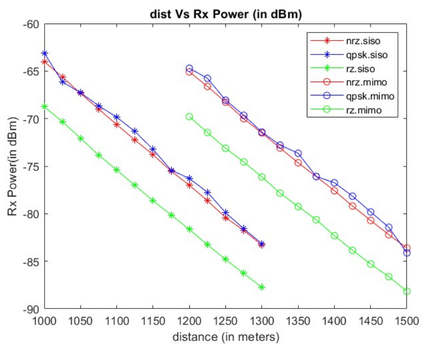

Figure 2.19: SISO VS MIMO with respect to received power

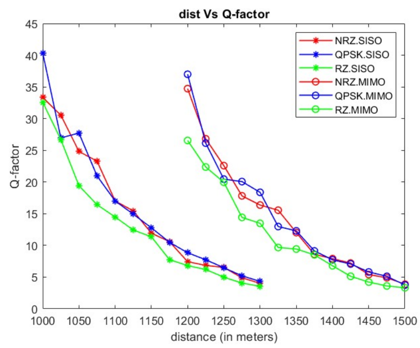

Figure 2.20: SISO VS MIMO with respect to Q-factor

Figure 2.21: SISO VS MIMO with respect to Received power and Q-factor

Chapter 3

Interference due to Ambient Light

Ambient light refers to the natural, existing light present in an environment. It is the general illumination that comes from sources such as the sun, sky, or artificial lighting in a given space. Ambient light provides a baseline level of illumination, allowing us to perceive and navigate our surroundings.

Effect of ambient light on VLC system are listed below:

1. Interference with Communication Signal: Ambient light, especially from natural sources like the sun, can introduce interference with the transmitted VLC signal. This interference may lead to signal degradation and increase the Bit Error Rate (BER).

2. Dynamic Changes in Illumination: Changes in ambient light levels throughout the day can cause variations in the overall illumination of the environment. VLC systems may need to adapt to these changes to maintain reliable communication.

3. Spectral Overlaps: The spectral characteristics of ambient light may overlap with the wavelength of the VLC signal. This can result in spectral interference and may require careful selection of transmission wavelengths to avoid conflicts.

4. Impact on Signal-to-Noise Ratio (SNR): Ambient light contributes to the overall background illumination. In some cases, it may increase the noise level, affecting the Signal-to-Noise Ratio (SNR) of the VLC system. A lower SNR can make it more challenging to detect and decode the communication signal.

5. Selective Absorption and Scattering: Different materials in the environment, such as windows or atmospheric particles, can selectively absorb or scatter certain wavelengths of light. This absorption or scattering can affect the transmission of VLC signals, especially if they fall within the absorbed or scattered wavelengths.

6. Challenges in Low-Light Conditions: In low-light conditions, ambient light may not provide sufficient illumination for VLC systems to operate effectively. This can be a challenge, particularly in scenarios where consistent communication is required in varying lighting conditions.

There are few methods to mitigate the interference caused by ambient light and they are;

1. Wavelength Selection: Choose transmission wavelengths that minimize interference with ambient light sources. Selecting wavelengths in parts of the spectrum where ambient light is less intense can help reduce interference.

2. Narrowband Filtering: Use narrowband optical filters to isolate the VLC signal from ambient light. These filters can be designed to transmit specific wavelengths associated with the communication signal while blocking unwanted ambient light.

3. Light Emitting Diode (LED) Dimming: Implement LED dimming techniques to control the intensity of the VLC signal. This can be coordinated with ambient light conditions to reduce interference during periods of high ambient light.

4. Multiuser Communication: Design the VLC system to support multiuser communication, allowing multiple users to share the communication channel simultaneously. Advanced multiple access schemes can be employed to manage interference.

MIMO (Multiple Input, Multiple Output) technology can be employed to achieve multiuser communication, where multiple users can simultaneously transmit and receive data over the same frequency channel. As discussed in previous chapter MIMO systems use multiple antennas at both the transmitter and receiver, allowing for spatial multiplexing and enabling the concurrent transmission of independent data streams to different users.

3.1 Circuit Design

3.1.1 Optisystem

In Optisystem, the above block diagrams are implemented as the following circuits in which figure 3.1, 3.2, 3.3 depicts SISO systems under the influence of ambient light with NRZ, RZ, QPSK line coding techniques respectively.

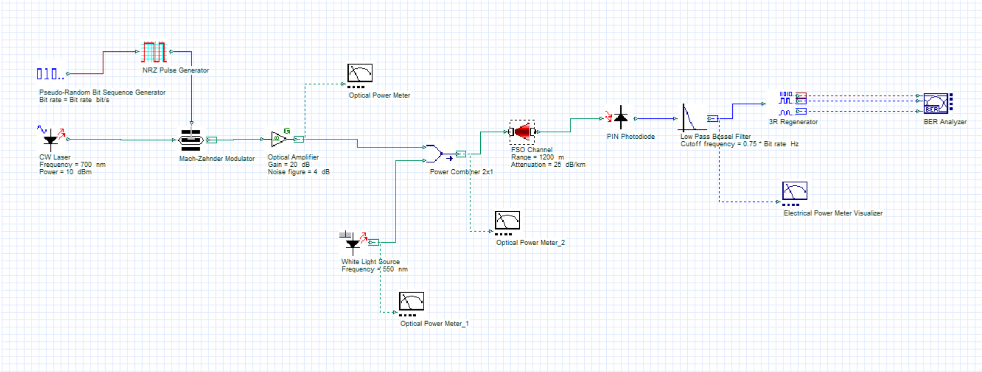

Figure 3.1: SISO NRZ system with interference

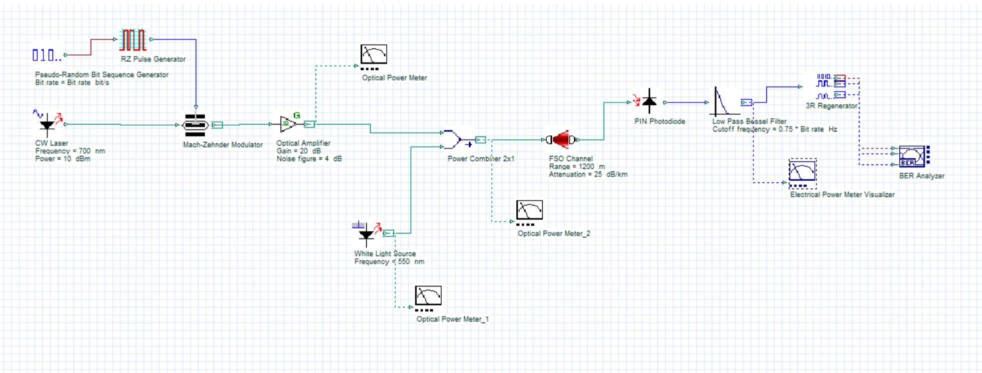

Figure 3.2: SISO RZ system with interference

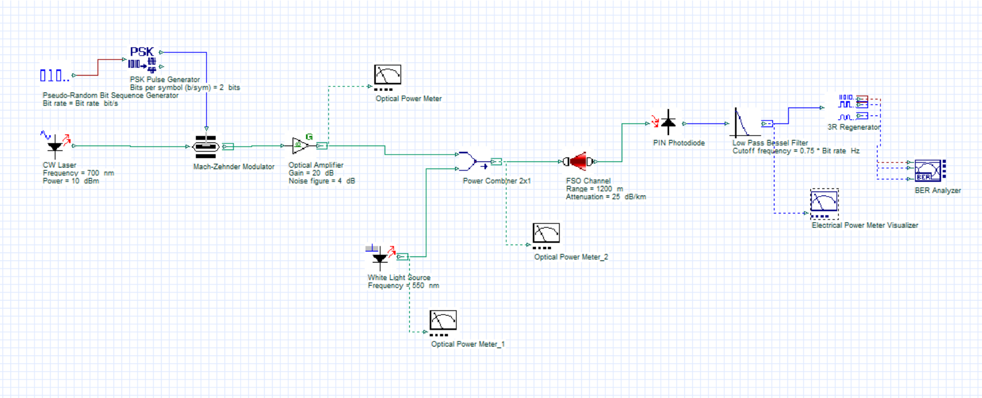

Figure 3.3: SISO QPSK system with interference

Similarly, figure 3.4, 3.5, 3.6 depicts MIMO systems under the influence of ambient light with NRZ, RZ, QPSK line coding techniques respectively.

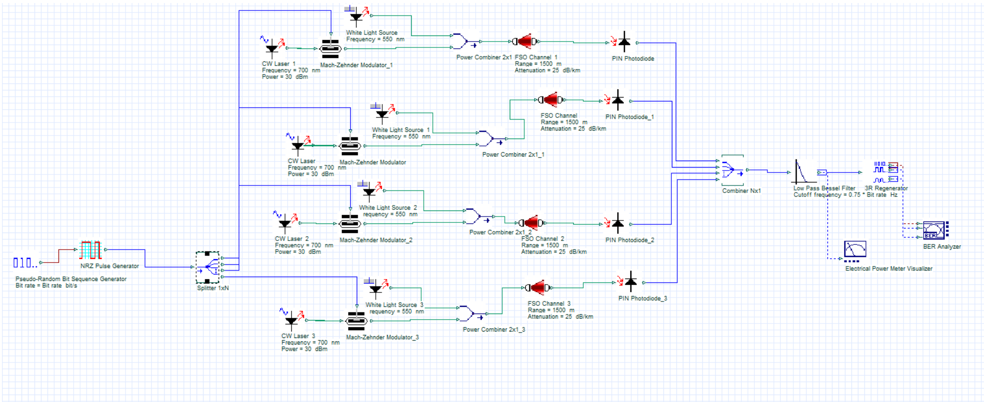

Figure 3.4: MIMO-NRZ system with interference

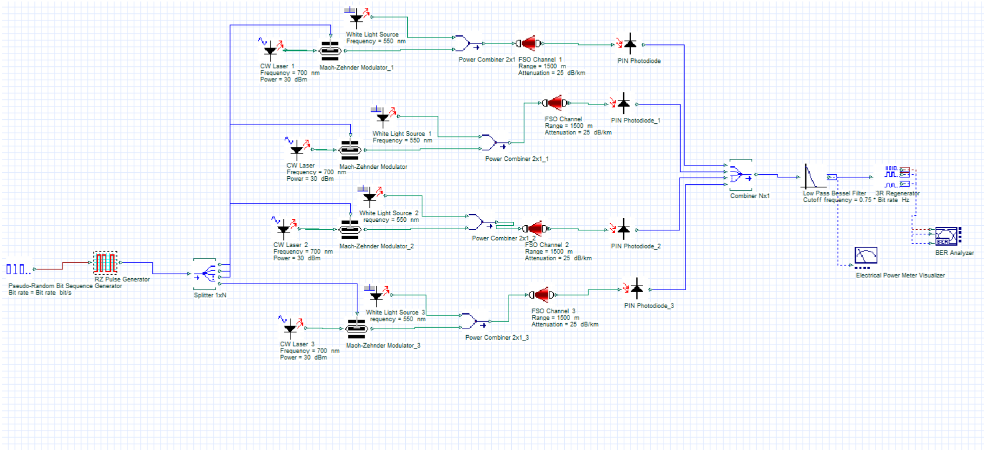

Figure 3.5: MIMO-RZ system with interference

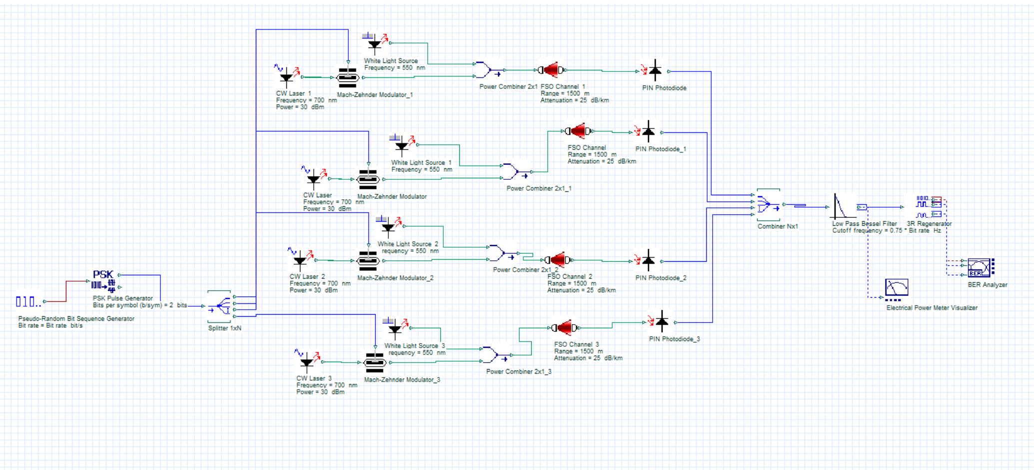

Figure 3.6: MIMO-QPSK system with interference

3.2 Performance Analysis

To compare the performance of each system, Bit Error Rate BER and received power are takes as metrics with following parameters

Parameters	Values/ Range
Datarate	1 Gbps
Power of LASER	30dBm
Wavelength of LASER	700nm
Wavelength of Ambient Noise	700nm
Channel attenuation	25dB/km

Table 3.1: Parameters table including interference

Observed values are plotted between distance and log10(BER), received power and Q-factor.

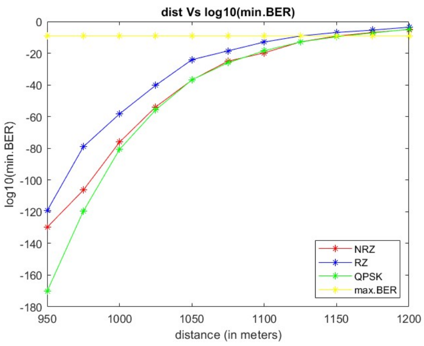

Figure 3.7: BER comparison in SISO system under the influence of ambient light

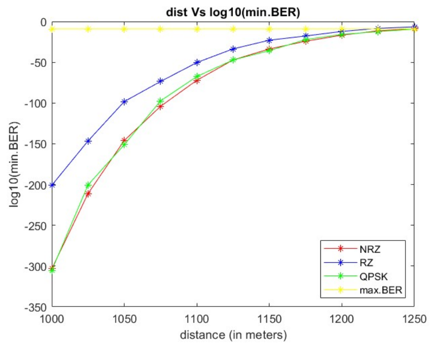

Figure 3.8: BER comparison in MIMO system under the influence of ambient light

Figure 3.9: BER comparison in SISO and MIMO systems under the influence of ambient light

From figure 3.7 and 3.8, RZ line coding techniques reaches maximum BER value allowed with in less distance. Hence it is has the least performance index, whereas NRZ and QPSK performs almost close to each other. Also, QPSK performs well than NRZ at lower distances.

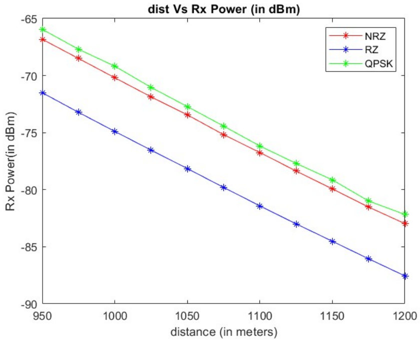

Figure 3.10: Received power comparison in SISO system under the influence of ambient light

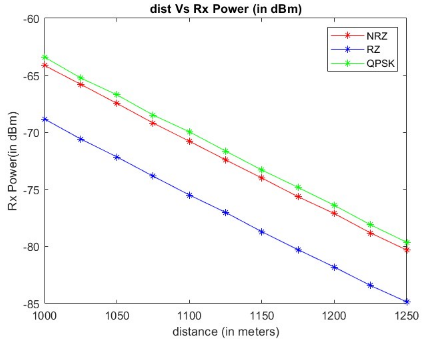

Figure 3.11: Received power comparison in MIMO system under the influence of ambient light

Figure 3.12: Received power comparison in SISO and MIMO systems under the influence of ambient light

From figure 3.10 and 3.11, with RZ line coding techniques power is received very less than the others. Hence it is has the least performance index, whereas QPSK outperforms NRZ here.

From the figure 3.7 and 3.8, there is a limit to the link distance is observed. After the limit BER is greater than 1/datarate, which is not acceptable.

Line Coding	Achievable Link Distance
NRZ	nearly 1150m
QPSK	nearly 1125m
RZ	nearly 1150m

Table 3.2: Achievable Link Distance in SISO Systems under the influence of ambient light

Line Coding	Achievable Link Distance
NRZ	nearly >1250m
QPSK	nearly >1225m
RZ	nearly nearly 1250

Table 3.3: Achievable Link Distance in MIMO Systems under the influence of ambient light

As shown in the above tables 3.2 and 3.3, MIMO achieves longer distance than SISO system.

Chapter 4

Future Work

4.1 Drawbacks

In the transmission only one line Of Sight LOS is considered both SISO and MIMO systems. But in real life situations, signal follows multiple paths. Also, all the observations are made at 1Gbps only, but VLC system can be used to transmit at few tens of datarate.

4.2 Futher Development

1. Both Light Of Sight LOS and Non-Light of Sight Non-LOS situations should be considered. May be cross-path between a transmitter antenna and non-opposite receiver antenna.

2. Transmission at higher datarates can be a potential area of study.

3. Orthogonal Frequency Division Multiplexing OFDM, which is stated to be resistant to interference can be implemented.

4. Sometimes working with LASER is harmful to living cells. Switching to LED for shorter ranges, broadcasting purposes is good idea.

Chapter 5

Conclusion

5.1 Conclusion

In this comprehensive study, we conducted a comparative analysis of Single Input, Single Output (SISO) and Multiple Input, Multiple Output (MIMO) communication systems employing three modulation schemes: Non-Return to Zero (NRZ), Return to Zero (RZ), and Quadrature Phase Shift Keying (QPSK). The investigation aimed to assess the performance of these systems under different conditions, including varying modulation schemes and the influence of ambient light.

Results indicate that MIMO systems consistently outperformed SISO counterparts in terms of distance coverage. The spatial diversity offered by MIMO allowed for effective transmission over longer distances compared to SISO configurations. Additionally, the analysis revealed a hierarchy in the effectiveness of modulation schemes, with NRZ and QPSK exhibiting superior performance over RZ, especially in the MIMO context.

Among the modulation schemes, NRZ and QPSK consistently demonstrated better performance in terms of signal reliability and distance coverage. These schemes proved more robust in the face of channel impairments and were particularly effective in MIMO systems. RZ, on the other hand, exhibited limitations, showcasing reduced effectiveness, especially in SISO configurations.

In environments influenced by ambient light, our study unveiled MIMO systems as more resilient to interference compared to SISO configurations. The spatial diversity inherent in MIMO played a pivotal role in mitigating the effects of ambient light, allowing for reliable communication even in challenging lighting conditions. Additionally, the modulation scheme analysis under ambient light reaffirmed the superiority of NRZ and QPSK in both SISO and MIMO setups.

5.2 Inference

1. MIMO for Extended Distances: Given the superior performance of MIMO systems in terms of distance coverage, we recommend the consideration of MIMO technology for applications requiring extended communication ranges.

2. Modulation Scheme Selection: The choice of modulation scheme significantly impacts system performance. NRZ and QPSK emerged as robust choices, particularly in MIMO configurations, offering reliable communication in diverse scenarios.

3. Adaptive Strategies: Implementing adaptive strategies that dynamically adjust modulation schemes and system configurations based on environmental conditions, including ambient light levels, can further optimize performance.

In conclusion, this comparative analysis provides valuable insights for designing robust and efficient communication systems. The study underscores the advantages of MIMO technology and emphasizes the critical role of modulation scheme selection in achieving reliable communication under varying conditions. As technology continues to advance, leveraging these insights can contribute to the development of more resilient and high-performing communication systems.

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