Performance Analysis of a Lifi System Based on VLC Over a LOS Channel with and Without Ambient Light Using Opti System

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Li-Fi (Light Fidelity) stands as a state-of-the-art wireless technology that sends data through light-based transmissions. Mobile robots require effective indoor location systems because they operate within hospitals, museums, and airport interiors. Researchers have studied the behavior of the On-Off Keying (OOK) modulation technique used in Li-Fi systems by observing the impact of background interference. Our model determines the performance of a 550 nm wavelength white LED transmitter using Opti System software. Evaluation of the system occurs through examinations under two conditions: when ambient light noise exists and when it does not. The research outcomes demonstrate that Li-Fi technology can deliver dependable high-speed indoor localization services for environments experiencing changes in ambient lighting conditions. Simulation findings indicate a Q factor measurement of 6.47 with noise, while the results show 19.18 when noise is not present. The network supports 10 Gbps data transmission at 2.96e-11 Bit Error Rate with ambient noise and 2.3e-82 Bit Error Rate with ambient noise under a 10-meter connection range.

On-Off Keying	OOK
Visible Light Communication	VLC
Radio Frequency	RF
Light-Emitting Diodes	LEDs
Free Space Optical	FSO
Pulse Amplitude Modulation	PAM
Quadrature Amplitude Modulation	QAM
Orthogonal Frequency-Division Multiplexing	OFDM
Color Shift Keying	CSK
Subcarrier Multiplexings	SCM
Pulse Width Modulation	PWM
M-Pulse Amplitude Modulation	M-PAM
Line-of-Sight	LOS
Non-Line-of-Sight	NLOS
Field of View	FOV
Non-Return-to-Zero	NRZ
Trans-impedance Amplifier	TIA
Signal-To-Noise Ratio	SNR
Bit Error Rate	BER
Visible Light Communication	VLC

Keywords: Lifi, Led, Los Channel, Optisystem, Wireless Communication

Introduction:

Wireless communication technologies changed the direction of multiple business sectors while creating better connection capabilities and enabling various novel uses. The field of wireless communication gains major promise through Li-Fi, which operates at high data speeds using visible light. Li-Fi operates under (VLC) as a distinct system that substitutes Radio Frequency (RF) systems through data transmissions that use (LEDs).

Mobile robots used extensively inside museums and airports as well as hospitals, and other facilities necessitate accurate and dependable indoor localization systems for operating effectively. Standard RF communication systems experience three substantial issues, including signal interference along with restricted bandwidth capabilities, and security vulnerabilities. The visible spectrum enabled VLC systems to present several benefits, such as enhanced bandwidth together with better security measures, and decreased electromagnetic disturbances.

Real-world VLC system performance suffers interference from ambient light sources, which constitute one of the system's operation-limiting elements. Noise from environmental light sources, including fluorescent lamps, makes the VLC system less efficient for its intended operation. Evaluation of VLC system performance requires understanding the impact of environmental noise elements during real-world operations.

The research uses OptiSystem to analyze the performance of a 10 Gbps Free Space Optical (FSO) communication system operating over a short-range Line-of-Sight channel by examining signal quality and bit error rate changes due to transmission distance variations, as well as optical filtering and component configuration selection. The research examines how the performance of 10 Gbps Free Space Optical (FSO) communication systems operates in short-range LOS channels by studying transmission distance and component configurations, and optical filtering. Opti system software allows the design of a VLC system simulation along with its analysis of a 36W fluorescent lamp operating at 50Hz ambient light noise source. The paper is split into distinct subsections for better clarity and consistent presentation. Section II explains the Visible Light Communication system principles through theoretical and modelling descriptions. The paper details simulation and evaluation techniques alongside a description of the methodologies that were employed in Section III. Section IV both displays the experimental findings as well as provides application insights into the research. The paper ends with Section V, which summarizes the main conclusions and evaluates the system's ability to achieve its goals.

Theory and Modeling of Visible Light Communication Systems:

The research on indoor Visible Light Communication (VLC) systems appears in this literature review [1] as it explores ways to enhance wireless communication in difficult settings, including hospital rooms and aviation cabins. Research into indoor VLC benefits greatly from Opti System simulation software, which enables optical communication system modelling and simulation [2]. Academic researchers use this controlled environment to conduct experiments regarding various network setups in addition to modulation techniques under different transmission circumstances. LED technology advancements have caused a major improvement in VLC system performance. The research by. [3] demonstrates how multi-level pulse amplitude modulation achieves several gigabit-per-second data rates.

The implementation of indoor VLC systems faces three main issues, which are specified in [4], namely interference as well as constrained mobility, and limited coverage range. The combination of signal processing algorithm advancement and modern modulation methods requires supporting technological improvements in optical receiver design to address the emerging challenges. The author employs Li-Fi technology that sends data through visible light communication according to reference [5]. Li-Fi provides better data rates and expanded bandwidth, together with electromagnetic interference resistance, when compared to standard wireless systems. Performance quality of Li-Fi systems heavily depends on modulation techniques because they influence product noise immunity alongside spectral efficiency and maximum data speed. Various techniques depicted in [6] serve a crucial function for this context, which includes On-Off Keying (OOK), Pulse Amplitude Modulation (PAM), Orthogonal Frequency Division Multiplexing (OFDM), and Subcarrier Multiplexing (SSM). According to Khalid et al. [7], ambient noise plays a crucial role in determining the performance of Li-Fi systems operating within an indoor setting. The importance of noise reduction depends on two key elements: equalization algorithms together with adaptive modulation.

The basic technique of OOK modulation functions as an encoding method in optical communication networks as described in [8]. The technology finds broad application due to its convenient operation and compatibility with different systems. Line of Sight (LOS) channels create unobstructed communication pathways for rapid long-distance data transfer through empirical evidence in [9]. Satellite communication systems, together with outdoor optical connections, find essential value in this technology. Investigatory studies [10] explored optical communication system susceptibility to ambient noise while developing techniques to minimize the noise, which enhances system performance and reliability.

Our paper explores the various advantages of Li-Fi technology invented by Harald Haas against Wi-Fi regarding bandwidth effectiveness and security, and availability [11]. Li-Fi enables fast wireless data transfer and dual-direction communication through its utilization of LED bulbs, as stated in reference [12]. Technology experts selected Quadrature Amplitude Modulation (QAM) as an optimal modulation approach because it delivers superior spectral efficiency. The wireless transmission methods consist of On-Off Keying (OOK), Pulse Position Modulation (PPM), Orthogonal Frequency-Division Multiplexing (OFDM), and Color Shift Keying (CSK).

Li-Fi operates across numerous applications, including wireless mobile networks, together with intelligent lighting technology for education purposes and traffic management functions. [13] The investigation focuses on VLC system development methods. VLC systems employ LED light emission because they deliver a longer operational lifetime as well as lower electricity demand. The paper reviews technological simulation models together with applications and past research, as well as existing difficulties in this field. Reference [14] demonstrates recent successes in VLC with high data rates, which emphasizes receiver illuminance assessment in system design while extending the communication coverage to 40 cm.

In the study mentioned in reference [15], reliable modulation schemes for optical communication systems are evaluated through an examination of the application of On-Off Keying Non-Return-to-Zero (OOK NRZ) modulation in a simulated environment. It considers several factors, including photo efficiency, bandwidth, interference susceptibility, cost-effectiveness, and production viability. In the meantime, research described in reference [16] uses Opti System 15 and MATLAB for simulations to evaluate the performance of Li-Fi communication under various modulation techniques and ambient noise conditions. According to this study, QPSK, or quadrature phase shift keying, performs better in typical lighting situations.

Effective modulation techniques like Subcarrier Multiplexing (SCM), On-Off Keying (OOK), Pulse Width Modulation (PWM), M-Pulse Amplitude Modulation (M-PAM), Orthogonal Frequency Division Multiplexing (OFDM) variants, and unique color domain modulation are required for Li-Fi, which combines LED communication with illumination [17]. The design and simulation of Line-of-Sight (LOS) and Non-Line-of-Sight (NLOS) multipath VLC models using LEDs are examined in this study [18], with particular attention paid to elements like transmission quality, reflection, and Field of View (FOV). Utilizing a spectrum 100,000 times larger than radio frequencies, Li-Fi technology in [19] enhances overall performance, power efficiency, and data throughput. With transfer rates of up to 2 GB/s, this makes wireless data transfer quick and affordable, which makes it perfect for critical environments.

LEDs are used in Li-Fi, a cutting-edge wireless technology, to send data across the visible light spectrum. Numerous advantages come with this method, such as increased speed, low latency, increased security, and a wider range of applications. Li-Fi applies to a broad range of platforms and industries and has the potential to solve issues like radio-frequency bandwidth limitations [20].

The cutting-edge optical wireless communication technology known as VLC has the potential to completely transform green lighting. Through the provision of both illumination and data transmission, VLC makes use of the visible light spectrum, which extends from 380 nm to 780 nm in wavelengths. White LEDs serve as the light source, a free space channel serves as the transmission medium, and a photodetector serves as the receiver in a typical VLC system. Compared to traditional fiber optic cables, the use of a free space channel offers several advantages, such as the removal of physical cables, lower installation costs, faster data transmission speeds, and the prevention of RF interference in research [21].

The present literature review looks at several problems related to systems for VLC. Many applications depend on the basic idea of using an LED source in VLC systems. Comparing LED lighting to traditional illumination systems reveals advantages like lower power consumption and longer lifespan. To better assess the performance of VLC, this review [22][23] aims to provide a thorough understanding of its various facets and to simulate a VLC system model.

This review aims to explore the essential ideas, real-world uses, and intrinsic difficulties related to VLC. The intricacies and auspicious potential of VLC technology are examined, along with simulation tools designed specifically for VLC systems, the incorporation of VLC in audio and video transmission, cutting-edge encryption techniques employing light-emitting diodes, and the potential application of VLC in vehicle-to-vehicle communication. Within the various applications of VLC systems, important challenges like reaching high data rates, extending transmission ranges, optimizing Line-Of-Sight (LOS) conditions, and mitigating interference are critically analyzed in [24][25][26].

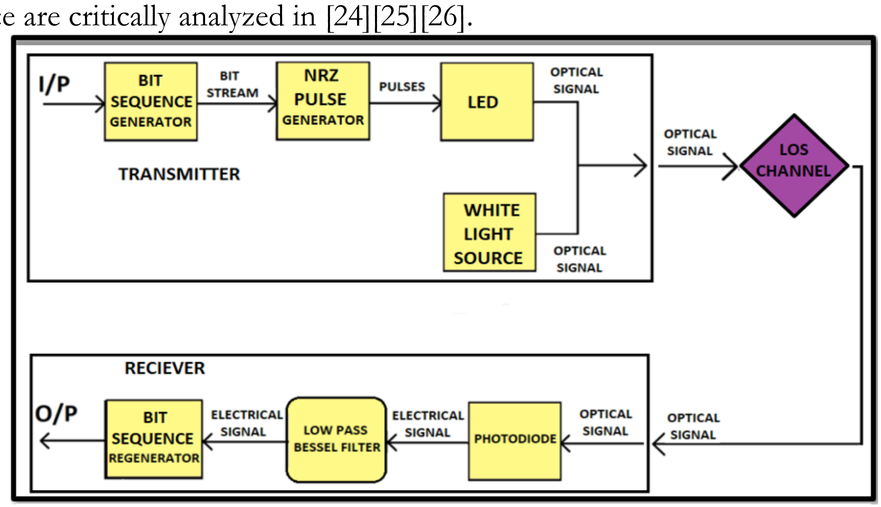


Figure 1. Block diagram of the lifi system los channel with ambient light.

The Methodology and Simulation Technique:

The research methodology uses OptiSystem to evaluate a Visible Light Communication Wi-Fi system through environment modeling between room characteristics and ambient noise levels, followed by system configuration design within the software. The system chooses light sources together with photodetectors as well as modulation approaches.

The simulation process generates performance data that contains received optical power combined with bit error rate alongside signal-to-noise ratio. The signals undergo an iterative optimization process that enhances their quality and reliability level. The research implemented Li-Fi technology for the development of a Visible Light Communication system. A system's block diagram under the influence of ambient light follows below in Figs and 2.

Transmitter Side:

The transmitter side of an optical communication system holds all the required pieces and operations needed to convert digital data to optical signals suitable for transmission through a wireless channel. The simulation used a sampling rate of 64 GSa/s to achieve a precise representation of the 10 Gbps signal. The optical spectrum operates within 1530 nm to 1565 nm (C-band) while featuring 1550 nm as the center wavelength and using Gaussian filter and bandpass filter components to reduce signal spectral width. A random binary bit sequence enables the system to produce data signals for simulation purposes. The transmission of digital data as binary bits (0s and 1s) begins after formatting by the bit sequence generator. The functional operation of optical communication systems relies on light pulse transmission instead of electrical signals, so encoding methods become fundamental for system operation. The process uses it for data encoding. The device implements Non-Return-to-Zero (NRZ) pulse creation for digital data transmission encoding. An electrical pulse generation tool that implements the NRZ encoding strategy operates under the name Non-Return-to-Zero (NRZ) pulse generator. Digital data streams use NRZ encoding to portray each bit value by specific pulse forms, together with low or high voltage levels. The data transmission indicates a '1' bit through a high voltage pulse or a pulse, while the '0' bit corresponds to a low voltage state or no pulse at all. The device serves as an optical transmitter that sends light signals according to the encoded data. The conversion of electrical energy into light happens efficiently through LED devices. The high efficiency of VLC systems depends on this feature that optimizes the conversion of data signals into light signals.

LOS Channel with and without the influence of ambient light:

Transmission between a sender and receiver takes place through LOS when their optical signal passes directly toward each other with no obstacles to impair it. VLC relies on unobstructed optical signal transmission of visible frequencies between light and photodetector devices. Design and optimization of VLC systems require LOS channels to attain efficient and reliable communication operation. Such predictions enable the evaluation of signal strength, together with coverage parameters, along with expected obstacles present in the LOS link.

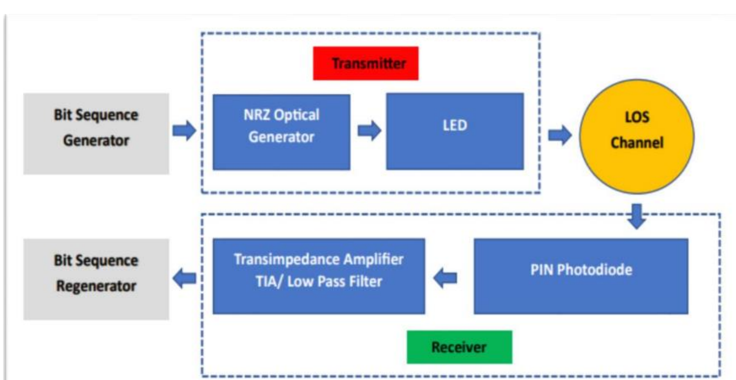


Figure 2. Block diagram of the lifi system los channel without ambient light

Several elements that affect LOS propagation in VLC systems require equal attention to their maintenance: 1. The maximum intensity of LOS signals occurs when the distance remains short. The rise in distance leads to reduced signal strength because of dispersion, together with attenuation. 2. Weather conditions that include fog, rain, and humidity create

LOS propagation complications by scattering light and through absorption of radio waves. 3. Within LOS paths, physical barriers such as walls, together with furniture and human bodies, can create signal strength reduction and quality deterioration. 4. The quality of the LOS signal depends on transmitter power output, alongside receiver sensitivity, as well as the selected optical system components.

Receiver Side:

A photo detector receives communication signals at the receiver end of the system. These signals need to undergo several conditioning processes, including amplification together with filtering, as well as frequency conversion to boost quality standards while suppressing noise disturbance. Demodulation systems extract the modulating signal through procedures matching the OOK modulation pattern. Signal extraction occurs with precision while the signal becomes ready for decoding at the next step. Components: 1. The Semiconductor devices known as PIN photodiodes serve three functionality areas, including optical communication, imaging, and sensing operations. They transform light signals into electric signals by utilizing semiconductor bandgap energy properties. 2. The Transimpedance Amplifier (TIA) operates as a device that converts sensor-generated current into voltage outputs when working with current signaling photodiodes. The performance stability of multiple other operational amplifier circuits becomes clearer using this fundamental building block. 3. A low-pass Bessel filter removes noisy high-frequency outputs, which tend to affect amplified electrical signals. The signal-to-noise ratio receives an improvement due to the filtering process that removes unwanted noise. The signal filter system follows Bessel patterning to maintain signal quality while eliminating unwanted signals. 4. The 3R Regenerator completes three operations for bit stream recovery: re-amplification followed by reshaping, and retiming. The combination that accomplishes re-amplification, reshaping, and retiming functions goes by the name 3R regenerator, as shown in Figs. 3 and 4 with and without the influence of ambient light.

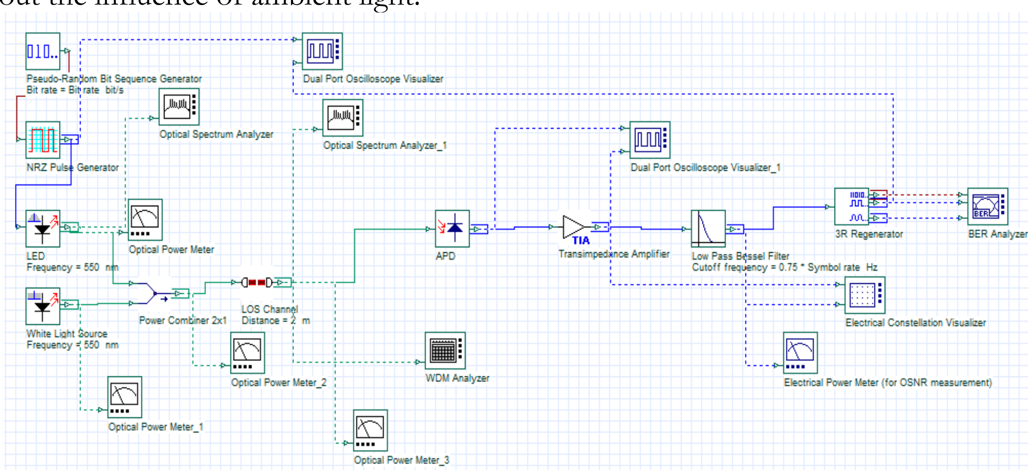


Figure 3. Simulation for the Los channel model with ambient light using optisystem software

The measurement of optical signal quality depends on OSNR, which stands for Optical Signal-to-Noise Ratio, through the comparison between signal power and noise power within the signal spectrum. Good signal quality depends on higher OSNR since it decreases interference from noise, which allows reliable optical communication. The decibel chart (dB) determines the measurement in equation 1.

$$\mathrm{OSNR} = 10\log10PsignalPnoise \quad (1)$$

The form presents P signal as the optical signal power and P noise as the noise power within the signal band. The Signal Power is 27.95 W and Noise power is 230.83 ×10-6 so the OSNR is 50.83 dB.

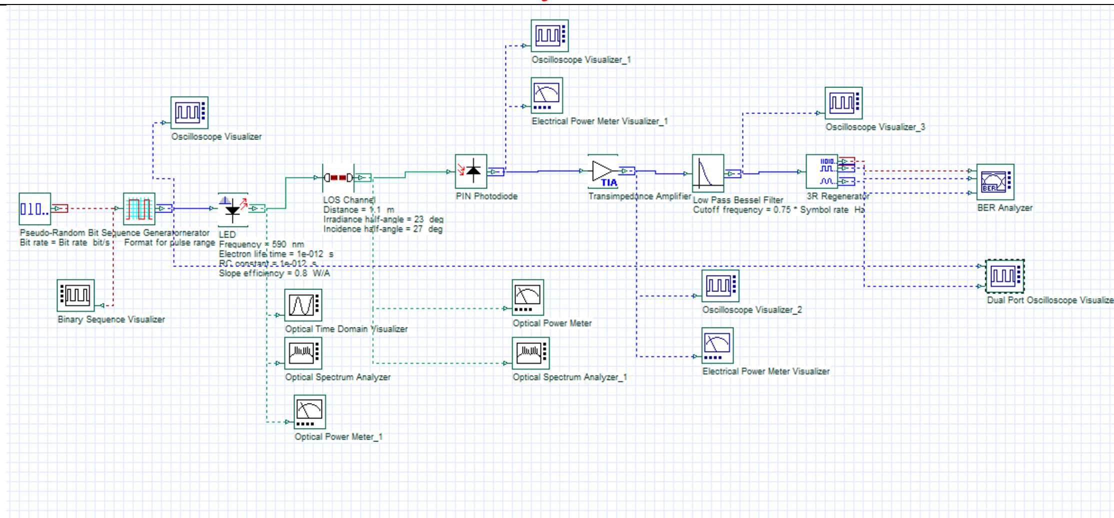


Figure 4. Simulation for the Los channel model without ambient light using optisystem software

Output Visualizer Components:

The research utilizes multiple visualization devices consisting of oscilloscope visualizers, binary sequence visualizers, optical power meters, optical spectrum analyzers, optical time domain visualizers and electrical power meters, and BER analyzers. Visual assessment of electrical signals occurs through oscilloscope displays, while binary sequence displays show binary code sequences. The combination of optical power meters and optical spectrum analyzers, and optical time domain visualizers provides data for measuring power levels and identifying signal components, as well as waveform capture in time domain measurement. Digital communication system performance evaluation, as well as energy measurements, result from the electrical power meters' functions. The analysis for Line-of-Sight uses Table I to present complete specifications of its components.

Table 1. The Component Parameters Of VLC-Based Li-Fi Loss Channel During Ambient Noise Manifestations

Component	Value
Bit rate	Bit rate = 10Gbp
Modulation Technique	(NRZ) OOK modulation
CW Laser source 1	Frequency = 550 nm Power = 1-10 dBm measure at 4dbm
White Light (Ambient Noise	Frequency = 50 THz Avg. Power = 4.6 mW
LOS Channel	Range = 10m underwater Frequency = 550 nm
Pin Photodiode	Type of Responsivity = Silicon Responsivity = 1 A/W Dark Current = 10nA Short Noise Distribution = Gaussian
Bessel Low Pass Filter	Cutoff frequency = 0.75 × symbol rate
Trans-impedance Amplifier (TIA)	Open-loop Voltage Gain = 90 dB

Results and Discussion:

Measurement of bit error rate relies on Gaussian algorithm processing between the BER analyzer and short bit transmissions. The BER (Bit Error Rate) Analyzer stands as a crucial assessment instrument for digital communication system performance evaluation in Opti-System. The main role of this tool relies on checking received and transmitted bits to detect errors, thus enabling to study of system performance dynamics across various situations.

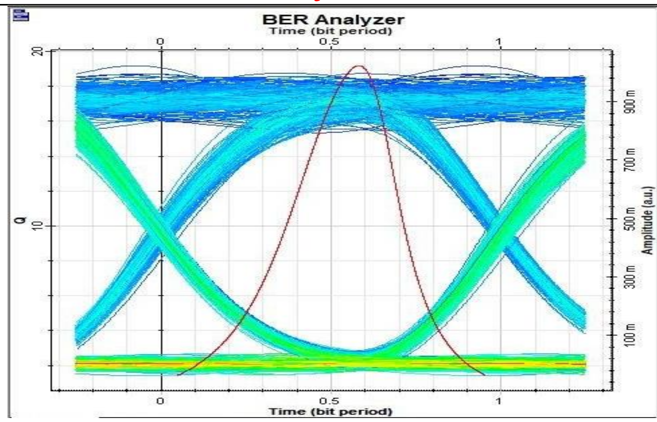


Figure 5. The BER Analyzer operated on VLC based LI-FI LOS channels with the influence of ambient light

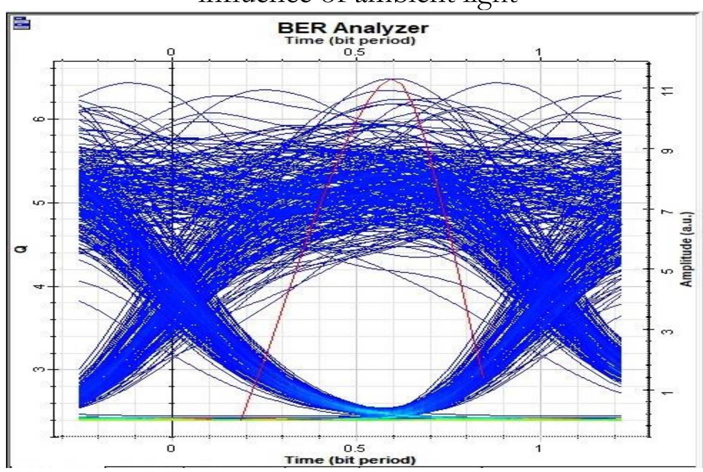


Figure 6. The BER Analyzer operated on VLC based LI-FI LOS channels without the influence of ambient light.

The BER Analyzer enables system design improvements for higher reliability and efficiency through analysis of modulation systems with channel effects and noise measurements, as well as error correction strategies. Performance metrics obtained from the BER analyzer enable strategic decisions when designing and testing systems. The quality assessment of optical signals within Opti-System relies on Q-factor measurements for determining both signal quality along system performance evaluation in optical communication systems. The Q-factor serves as an assessment tool for BER performance evaluation of systems, including fiber-optic communications and coherent optical systems, and serves us in analyzing our designed LOS channel.

The obtained quality factor meets the required threshold of 6, as it reaches 6.72 with the influence of ambient light and 19.18 up to 10 10-meter distance. Figures 5 and 6 show the results with and without the influence of the ambient light of the BER analyzer. The evaluation of system performance requires users to include input and output signals as results within the OptiSystem software. The input signal brings the original transmitted data to view, which enables users to access information about power level as well as wavelength and modulation format parameters, as in Figures 7 and 8. Analysis of system efficiency and losses, together with distortions, is possible when examining the output received data signal, which travels through different system elements. Users perform performance metric assessments through signal comparison, which includes signal-to-noise ratio (SNR), BER, and power variations assessment. The process of system optimization, along with enhanced signal quality, results from this signal comparison procedure as shown in Figure 9.\

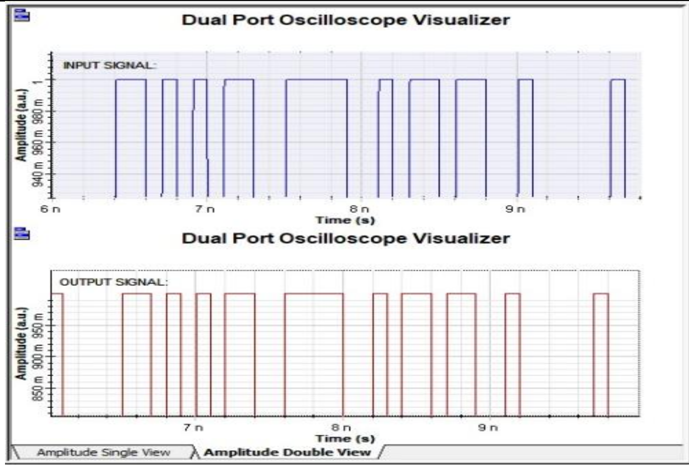


Figure 7. The results of VLC based LI-FI LOS channel simulation with ambient light show input and output signals through Oscilloscope visualizer. Comparison of Transmitted (blue color) and out received (red color) waveforms.

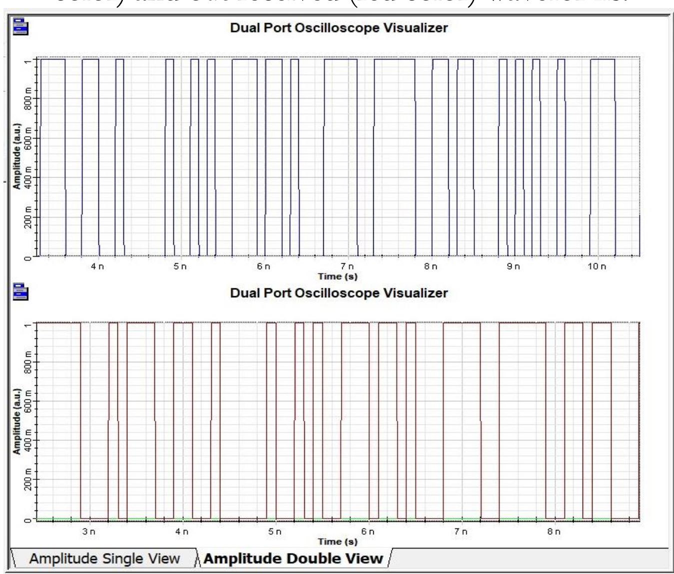
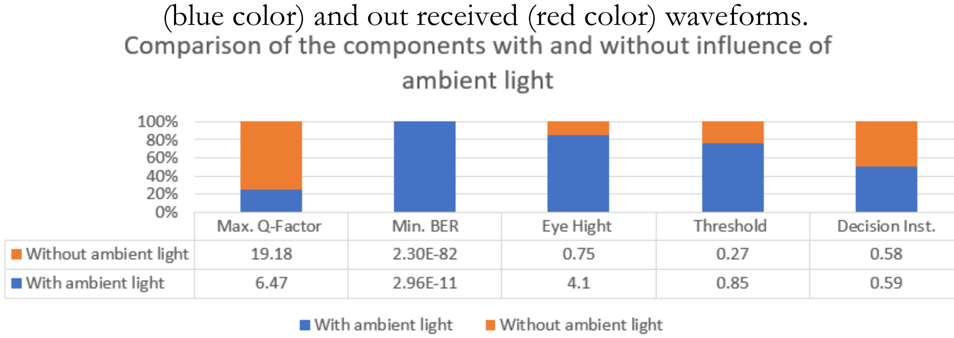


Figure 8. The results of VLC based LI-FI LOS channel simulation without ambient light show input and output signals through Oscilloscope visualizer. Comparison of Transmitted (blue color) and out received (red color) waveforms.



	Max. Q-Factor	Min. BER	Eye Hight	Threshold	Decision Inst.
Without ambient light	19.18	2.30E-82	0.75	0.27	0.58
With ambient light	6.47	2.96E-11	4.1	0.85	0.59

Figure 9. Comparison of the components with and without influence of ambient light

Conclusion:

The paper examines the effects of ambient noise on VLC Li-Fi channel performance through visible light communication (VLC) evaluation. The research analyzed systems through performance testing of OSNR and Q-factor along with BER. The research findings demonstrate an advancement in indoor communication systems since VLC technology delivers 10Gb/s transmission over 10m distances at 50.52 dB OSNR. The research develops a dependable VLC Li-Fi system that maintains 10Gb/s data rates during a 10 m distance while operating with OSNR equal to 50.52 dB. Los Channels perform. Under ambient conditions, the experimental system reached better results, indicating 2.96e-11-bit error rate and 6.47 Q factor; however, the results without ambient light showed 2.3e-82-bit error rate and 19.18 Q factor. The rectangular optical filter serves in the research to reduce the effects of uncontrollable ambient light on the signal system. This research establishes new opportunities for wireless communication technology development, which will foster progress within the wireless communication domain.

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