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Visible Light Communication System Architecture for Indoor Application Incorporating Forward Error Correction Code

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ABSTRACT

VLC (or visible light communication) has grown in popularity in recent years. For next-generation communication system upgrades, dependable data transmission is essential. As the number of VLC system users increases, so does the need for consistent, rapid, and minimally delayed data delivery. However, as more consumers demanded higher speeds, transmission errors also increased. The error correction code minimizes the overall system's data error to mitigate this effect. This study examines a design architecture for a visible light communication (VLC) transmission system that incorporates forward error correction code to improve error performances, suggesting its suitability as access points in 5G technology. The simulation uses version 17 of the Opti system. The proposed architecture employs the Reed Solomon code, a well-known forward error correction (FEC) channel encoding, to safeguard the base band signal throughout its transmission over an optical channel containing all visible background sounds. An optical filter and equalizer purify an incoming optical signal by eliminating harmonic components introduced by the VLC channel and restoring signal balance. The data transmission has utilized a forward error-correcting channel encoding of RS code with a non return to zero. The simulation modeled the white, spectral, red, yellow, green, and blue light to present various background sounds accessible via the VLC channel. The simulation results indicate that the system model obtains a typical level of zero-bit errors.

1. Introduction

Visible Light Communication (VLC) is an optical wireless communication system that transmits data using visible light as the carrier signal [1]. It enables simultaneous data transmission and illumination of a defined area, but only within a limited range. It is one of the finest uses for wireless communication in limited spaces due to its versatility. Nonetheless, it has many desirable characteristics, such as an unobstructed visible EM spectrum, high bandwidth, high security, human safety, energy efficiency, EMI resilience, and so on [1,2]. VLC architecture can be employed in vehicle

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technologies [3,4], 5G and 6G architecture as a complementing technology to existing wireless communication systems with high-speed data rates, such as cellular networks and Wi-Fi [2]. However, the communication path for these high transmission rate systems is typically very short [5, indicating the need for improvement to ensure the communication transmission is qualified for indoor spaces and illuminations]. As a result, Forward Error Correction (FEC) can be utilized in VLC architecture systems to enhance the bit error rate (BER) and boost system capacity. FEC is a technique for error correction widely used in digital communication systems, especially optical systems, to increase system reliability and performance [6-9]. FEC in VLC systems can provide various advantages, including higher performance, improved robustness, lower power usage, and cost savings [9]. Different FEC codes have different strengths and weaknesses, and the optical communication system's specific requirements and constraints determine the choice of FEC codes. Turbo codes are among optical communication systems' most often utilized FEC codes [10,11]. *C. C. Chen et al*., [10] demonstrate that Turbo codes can produce significant performance improvements in optical communication systems, with BER reductions of up to [9,10]. The study also found that improving the code parameters and interleaving methods can increase the performance of Turbo codes. Low-Density Parity-Check (LDPC) codes are another type of FEC code extensively employed in optical communication systems [12-14]. *Y. Li et al*., discovered that LDPC codes could give good error-correcting capabilities with minimal overhead. This research also demonstrated that LDPC codes optimized for various optical communication systems for excellent performance. Another typical FEC code in optical communication systems is the Reed-Solomon (RS) code [15-17], according to the findings of *U. Sripati* [15], RS codes can provide good error-correcting capabilities with little overhead in optical communication systems.

Reed-Solomon codes work by introducing redundancy to the data sent. The sender separates the original data into blocks with a specified number of symbols each. These symbols can represent as numbers or characters, depending on the application. The sender then inserts additional symbols, known as parity symbols or check symbols, into each block. These symbols use mathematical calculations with the original data symbols [17]. The resulting symbol sequence, including the original data and parity symbols, is then sent via the communication channel. The received symbols may have mistaken due to noise, interference, or other causes at the receiver end. The receiver uses the Reed-Solomon decoding method to identify and repair faults in the received symbols. The decoding algorithm begins by examining the received symbols for mistakes. If defects that found, the procedure corrects them using parity symbols [17]. Based on the received and parity symbols, the program performs mathematical computations to estimate the most likely original data symbols.

VLC is becoming an increasingly significant technology for next-generation wireless communication systems due to its unique characteristics [18,19]. VLC can be viewed as another technology that may share spectrum with other communication systems, although it operates in the visible light range. Coexistence strategies used in RF networks (like adjusting ED thresholds) are conceptually transferable to VLC environments where multiple light sources or optical communication systems may interfere with each other [20]. VLC architecture can be utilized in 5G and 6G architecture to enable high-speed, low-latency connectivity for various applications, including mobile networks and Io T, as well as ITS and AR/VR. Besides that, On-off keying (OOK), pulse amplitude modulation (PAM), and frequency shift keying (FSK) can be also used to modulate the light signal. Multiple modulation and coding techniques might be used to analyzed the performance of a VLC system in a research simulation [21,22]. Lastly, the light-emitting diode (LED) or any other kind of light source that can modulate the signal to convey data may function as the light source in a visible light communication (VLC) system. A mathematical model replicating the modulation and intensity of the light signal can be used to model the light source in a simulation so that it can be modeled using a mathematical model. The model can be constructed based on the particular characteristics of the LED or other light sources, such as the spectrum response, emission pattern, and power output [23,24].

Using the simulation program Opti system version 17, we were able to propose and model the architecture of the VLC system, which included the inclusion of an RS code encoder and decoder at both the transmitter and the receiver. After then, an analysis of the system's performance was carried out. The following headings provide the best synopsis of the information presented on this page. In the same way, as the first portion offered a more in-depth discussion of a quick introduction to the study effort, the second section explained the suggested system design and schematic layouts and parameters—the outcomes obtained from the simulated architectural environment discussed in the third section. The final section presents the findings and inferences drawn from the preceding sections' worth of investigation and observation.

2. VLC System Architecture Setup

The light source, the optical channel, and the receiver are the three major components of visible light communication (VLC) systems. Figure 1 depicts the basic configuration arrangement for VLC in this work, which as access points in an indoor context. This diagram illustrates forward error correction (FEC) in a VLC access point, which connects end users in smart home structures to an extensive network—single-mode fiber used as the backbone for the transmission path from the central station (CS). The communication system for local area networks or indoor communication could be disseminated from the spine utilizing the VLC platform as access points (AP). A light-emitting diode (LED) or any other type of light source that can modulate the light signal to transfer data can use as the light source in a VLC system. White LEDs and power line communication (PLC) are also proposed as network backbone components, particularly in enclosed spaces. The FEC-VLC access point needs an optical amplifier to amplify the signal and make it feasible for the underlying architecture of the optical fiber network to reach the buildings. It is necessary to transmit the VLC signal to the users and amplify it before it transmits. On the other hand, because this particular aspect of the amplification is supposed to take place on the transmission backbone, it was omitted from the simulation. Before the actual data transmission occurs, the error correction method used in the forward direction is specified. The VLC transmitter at the central station is in charge of receiving the 10-Gigabit PRBS signal that is generated by the CS and then transmitted there. While encoding the PRBS signal, a forward error correction (FEC) channel encoder that utilized to cut down on the overall number of bit errors. Modulating a white LED source with an encoded binary signal is possible if one sends a signal that does not reset to zero at the beginning of each cycle. The VLC channel is subjected to all the visual ambient background noises to evaluate how effectively the proposed system operates with a noisy optical channel. These include red-light, green light, blue light, yellow light, ultraviolet light, and a spectrum light source. It will allow us to determine how well the proposed system functions with a noisy optical channel. It will provide insight into how effectively the proposed approach performs with a noisy optical channel, which is necessary for determining how well it functions. Rectangular optical filters utilize the signal received by the receiver of the VLC access point. This design can operate on a base band signal and is compatible with the 5G base band unit enforcement. As a result, it can provide services for clients of smart homes with direct VLC distant access points.

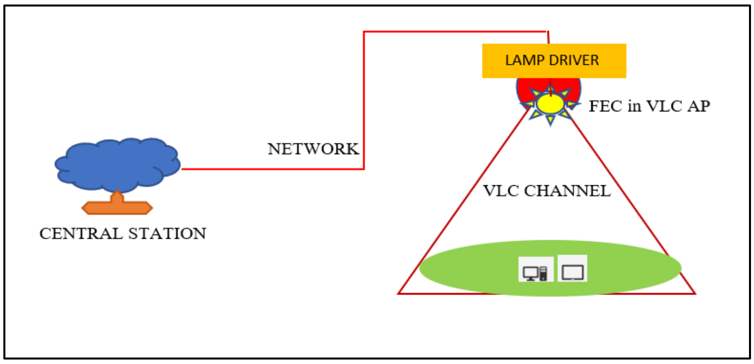


Fig. 1. Design visualization of VLC as indoor access point platform

Figure 2 shows the design's simulation layout shown in version 17 of the Opti system. Here are the transmitter, the optical transmission path, and the receiver, the three parts that comprise the suggested design's simulation model. The optical emitter comprises the LED source, a base band pseudo-random binary sequence (PRBS) signal generator, an FEC channel encoder, and a non-return to zero (NRZ) encoder. The optical receiver has a photo detector, an equalizer, a low pass filter, a 3R regenerator, and a BER analyzer. The second part of this layout describes the structure of the VLC channel as an entry point, which includes both the VLC channel and any background sounds made by optical devices.

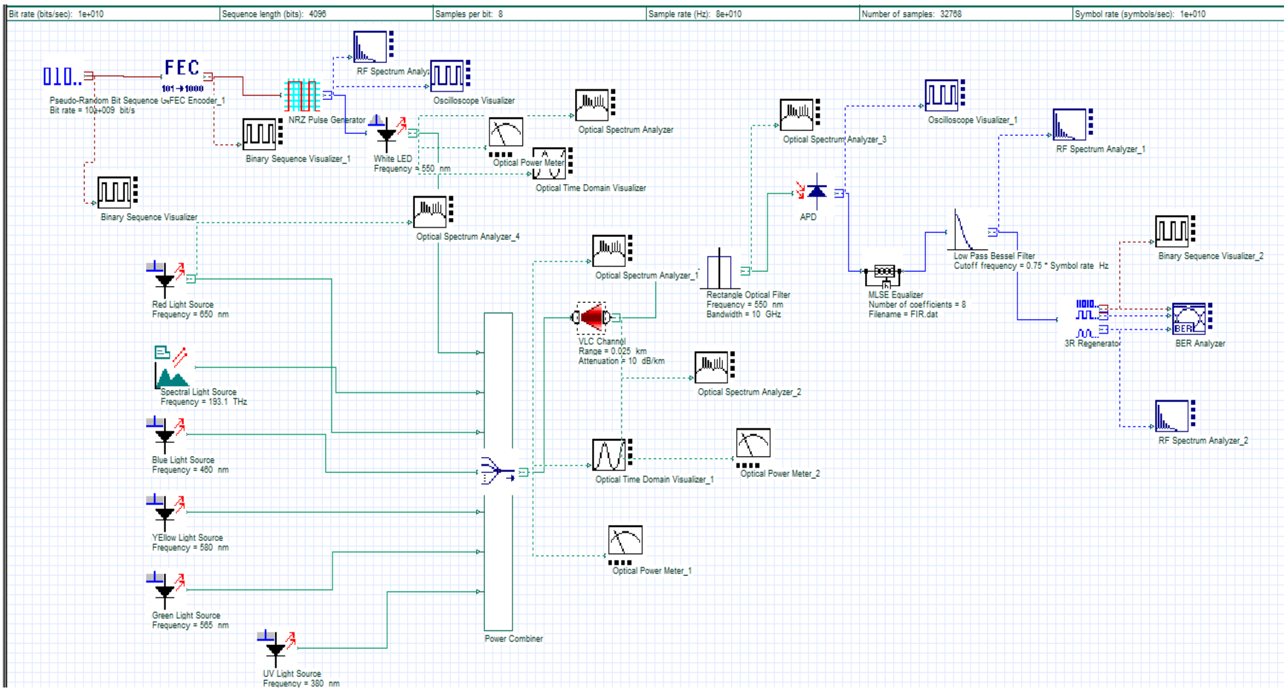


Fig. 2. The network architecture layout of a simple remote VLC incorporating indoor environment background noises

The detrimental effects of inter-symbol interference (ISI), brought on by the optical channel, can be mitigated thanks to the MLSE equalizer included in the design. An avalanche photo diode (APD) serves as a model for the photo detector that receives the optical beam at the other end of the channel and turns it back into an electrical signal. An FIR filter based on the Viterbi algorithm normalizes the recorded signal. After that, a low-pass Bessel filter with a 0.75-bit rate (Hz) cut-off is applied to the signal. This is done to separate the wanted electrical signal from the unwanted one.

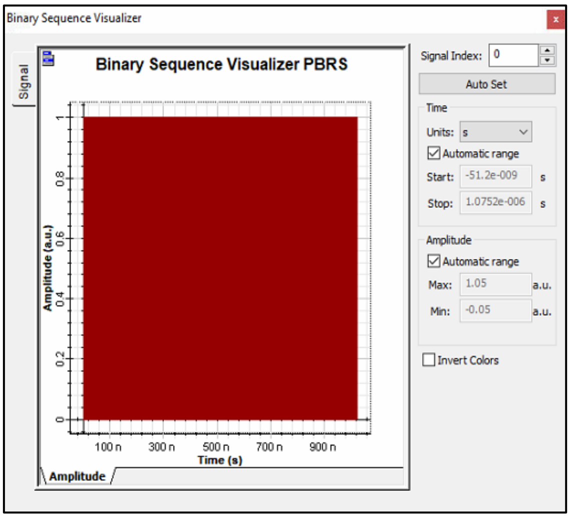
The suggested system's bit-error-rate (BER) is calculated after the intended signal is demodulated using a 3R regenerator. The simulation's settings are tabulated in Table 1.

Table 1
Setup parameters

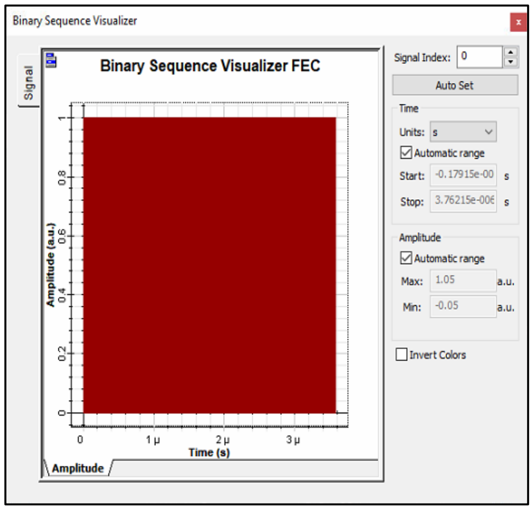
Pseudo-random binary sequence (PBRS) bit rates	10Gbps
White LED source	
Frequency	550nm
Electronic lifetime	1e-012
RC constant	1e-012
Slope efficiency	3 W/A
Background noises	
Green light source	565 nm
Blue light source	450 nm
Red light source	650 nm
Yellow light source	580 nm
UV light source	380 nm
Spectral light source	1552nm
VLC Channel	
Distance	25 m
Attenuation	10dB/Km
Rectangular optical filter	
Frequency	550 nm
Bandwidth	10 GHz
MLSE equalizer	2
Samples per bits	8
No. of coefficients	8
Avalanche photodiode (APD)	
Gain	3
Responsivity	1A/W
Low Pass Bessel Filter (LPBF Cut off frequency)	0.75*Symbol rate HZ

3. Simulation Results and Discussion

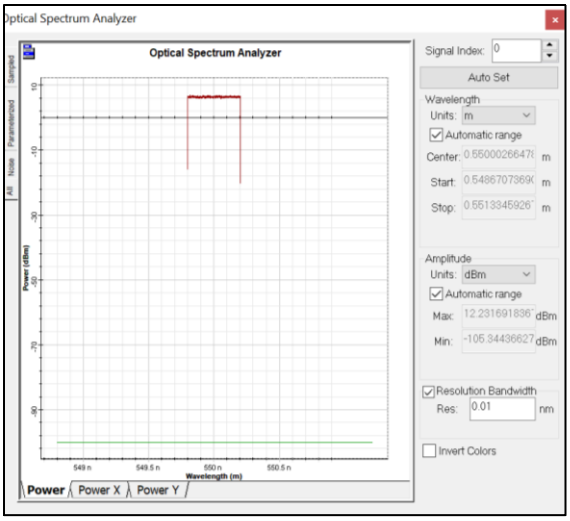
Figure 3 depicts the results observed during each phase of the simulation layout design for the transmitter component in version 17 of Opti system. The number of samples is 32768, while the sequence length for the schematic layout is 4096 bits. Figure 3a depicts the bit sequence data input to the PRBS signal at 10Gbps. Figure 3b illustrates the bit sequence transmitted by an FEC encoder employing the RS code. (7,2) is the RS code index for (N, K). Transferring through the FEC encoder adds parity bits to the sequence bits to reduce the number of error bits. The encoded binary signal is transmitted as a modulating format that does not return to zero to modulate the white LED source. Figure 3c depicts the base band signal transmitted over the VLC channel. The power spectrum of a white LED source is illustrated in Figure 3d.



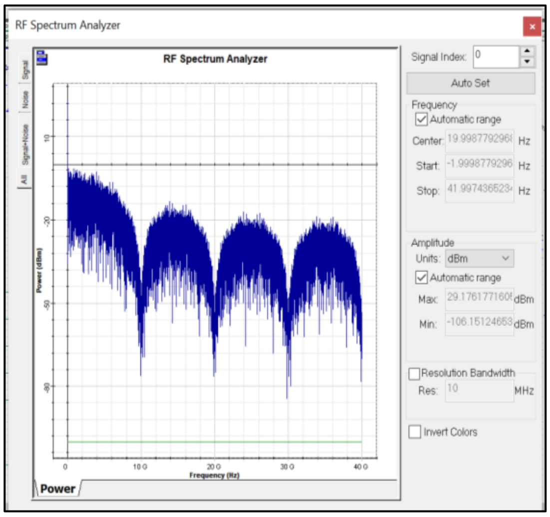
(a)



(b)



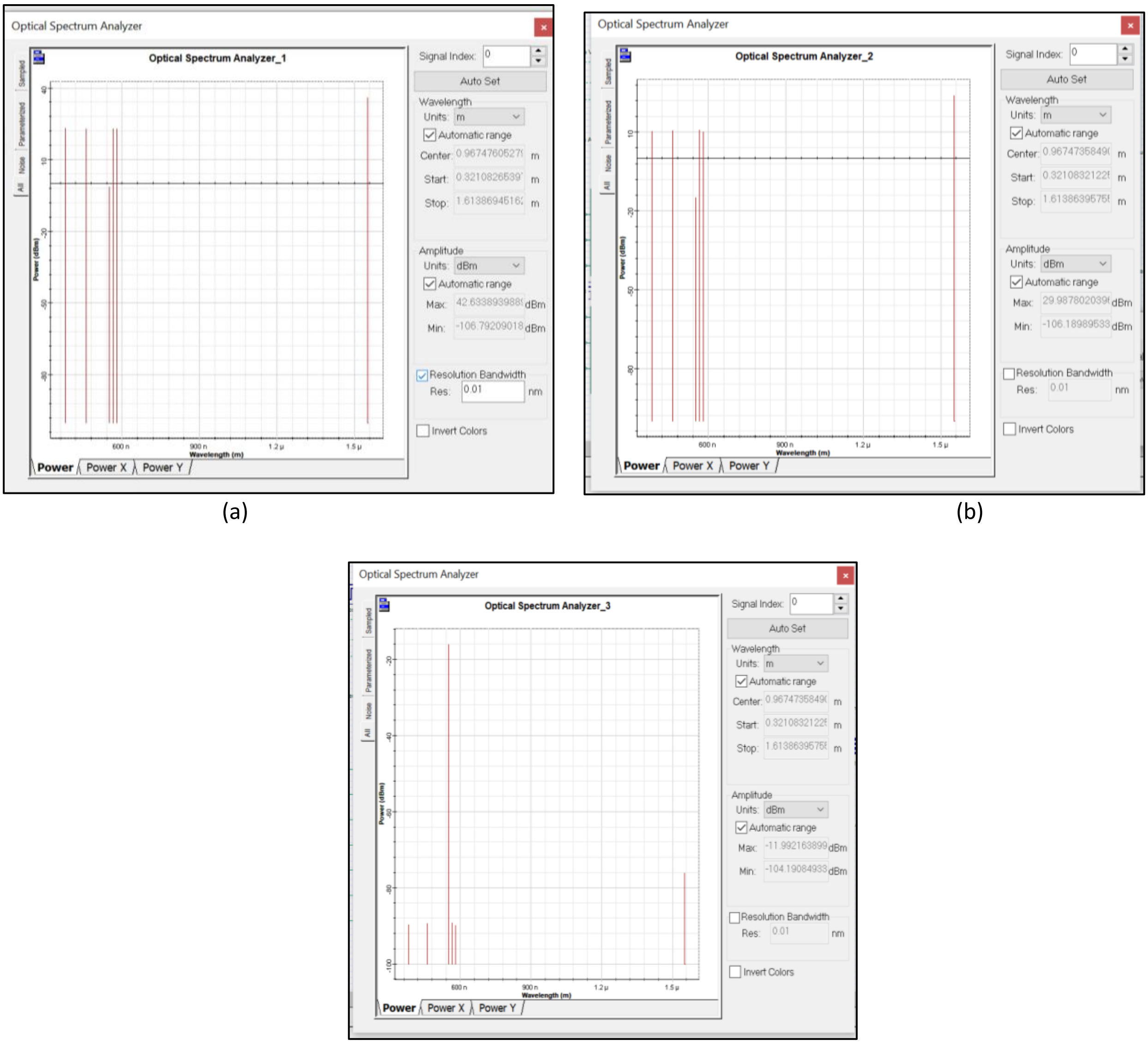
(c)



(d)

Fig. 3. Transmitter output observation from each phase (a) PRBS binary sequence (b) Binary sequence after RS code encoder (c) Frequency spectrum after non return to zero pulse generator and (d) Spectrum of white LED light source

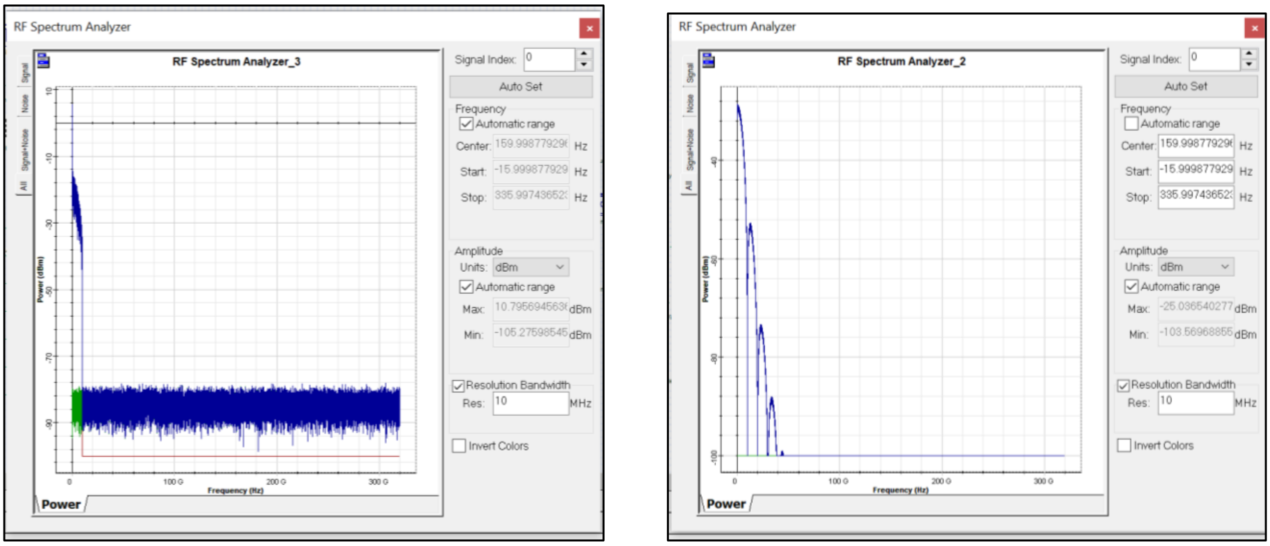
Figure 4 represents the data observed at the VLC channel path. These results contain all of the background noises, both visible and ambient. After a route of transmission that was 25 meters long, the power of all-optical signals began to decrease, as demonstrated in Figure 4(b). It is because the attenuation has been predetermined to be 10 dB/km, considering an inside setting. These optical signal spectra are sent through the rectangular filter to acquire the desired signal at 550 nm. At the same time, all other undesired signals are either decreased or filtered out in the process. Figure 4(c) illustrates the output produced by the rectangular filter. Only the signal at 550 nm was observed to have a significant amount of power here.



(a) (b) (c)

Fig. 4. Observation on the optical path. (a) Signals including all background noises. (b) Signals after 25m VLC channel path and (c) Data carrying signals after optical filter

Figure 5 illustrates the signal output that was observed from each output of the receiver's components. The electrical signal spectrum converted after the APD is shown in Figure 5(a). Figure 5 (b) presents the RF base band signal observed at the output end of the receiver.



(a) (b)

Fig. 5. Receiver output observation after each phase (a) RF electrical signal spectrum after photo detector and (b) Electrical base band signal received at the output

Figure 6 shows that the eye diagram of the VLC design that was studied and used the Reed Solomon code has a comprehensive and precise eye-opening. It means that the signal quality was good. This signal got a Q factor of 131502 and a bit error rate of 0 or less, so the success of this VLC system with FEC codes is a good sign that it can be used for indoor applications.

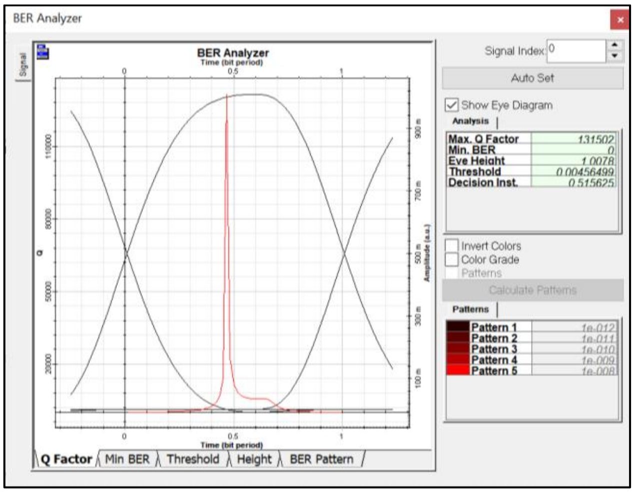


Fig. 6. BER and Eye Diagram performance of FEC-VLC communication system

4. Conclusions

The purpose of this study is to investigate how well a simple VLC architecture performs as a substitute implementation for wireless access points in indoor applications. The results indicated that this architecture is reliable and that it may perform well in reducing error rates. An appropriate approach that might be taken into consideration in real-world applications for smart homes and indoor networks is integrating the technology with FEC codes. Incorporation of FEC codes with VLC technology is a possible approach that might be taken into consideration, even if the technology may still have higher bit error rates at high speeds and data rates. As the demand for high-speed and dependable VLC systems continues to increase, additional research is required to develop FEC techniques that can accommodate the transforming requirements of VLC systems.

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