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Analysis of Visible Light Communication using Integrated Avalanche Photodiode

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Abstract

The problem with Radio Frequency (RF) communication is that it has intrusion and high remission. Moreover, RF communication requires distinct configurations for transference and reception. To overcome these problems, Visible Light Communication (VLC) is recommended, as it has a high tolerance for bandwidth and interference. The usage of LEDs instead of fluorescent lamps uplifts the use of VLC. Visible light communication is a fast-evolving LED-based illumination and data transfer method. The performance of visible light communication over Mach-Zehnder Modulation has been investigated in this paper using the Opti-system simulation tool. The opti-system simulation programme predicts the quality factor and Bit Error Rate (BER) values of various link distances. The proposed system can handle 5 Gbps data rate over a 50-meter link distance with a Quality Factor of 15.71 and no external noise. The projected VLC system performance is further tested using a simulation tool in the case of external noise effects.

Keywords: Avalanche Photodiode, Mach-Zehnder Modulation, Opti-system simulation, Visible Light Communication

1. Introduction

The expanding request for more bandwidth so as to provide high-quality mobile services to the expanding rate of internet traffic, and the implementation of Internet of Things have prompted extensive studies into novel transmission technologies [1]. New restrictions in terms of module downsizing, link coverage distance, less manufacturing cost, and less consumption of power have become crucial characteristics to address, adding to the predicted faster bit rates. Visible Light Communication has been prompted as a promising transference

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method for a wide range of indoor and outdoor functions [2].To improve transference capability, a variety of VLC transference technologies have been promoted. VLC is regarded as an essential eco-friendly information technology as a supplement to Radio Frequency (RF) transmission [3].

2. Related Work

Multiple VLC receivers based on Single Photon Avalanche Diode have formerly been described, and SiMPs/MPPCs with photon detection efficiency higher than 14 percent are claimed to produce more sensitive receivers than existing API-based receivers [4]. SiPMs with Photon detection efficiencies of higher than 40% in the blue section of the visible light spectrum have recently become accessible. They also feature output pulses of 1.5 ns, which are much shorter than other SiPMs or MPPCs available on the market. Based on the output pulses, the VLC receivers should be able to function at OOK rates of data which are higher than 100Mbps without substantial inter-symbol interference [5]. The sensitivity of SiPMs/MPPCs can be reduced by discrete SPADs when combined with ambient illuminance as it exhibits substantial characteristics such as dark count, after-pulsing and optical cross-talks. The trouble is to accomplish these higher rates of data while preserving a sensitivity constrained by statistical noise, often known as shot or Poisson noise [6].

Modulation strategies described for VLC systems confront difficulties like as flickering and dimming, which should be avoided since they might induce visible negative/harmful physiological changes in humans' eyes. Because there is no need to switch light currently, the use of an external modulator (MZM) can overcome the above-mentioned concerns [7]. It will be constantly on, with the modulator doing all of the switching. ER and IL are the most critical performance aspects of MZM. The difficulties might be in implementing these models in real-time VLC since the signal would also suffer from air loss. To boost data rate, an optical concentrator might be considered at the receiver side [8]. The VLC scenario has been used to test a variety of different materials and technologies to see how they perform in terms of fc, rr, and transmission data rate [9]. The f-3dB of blue LEDs and colour converters may reach 1485 MHz and 470 MHz, respectively, which is a significant increase above the 5 MHz fc of traditional white LEDs. Only a handful of the newly produced PDs have been explicitly described in fc, with the biggest being 4.2 MHz [9].

A relatively modest voltage of 11 V allows for the avalanche activity. The excess noise factor of the Avalanche Photo Diode (APD) has also been computed, which regulates its performance in the presence of Johnson noise from the receiver circuit [10]. The APD optical bandwidth can be enhanced by subdividing the active area in a meshed array, according to a speed comparison of large area APD architectures from 2-D device level modelling. For the first time, a bidirectional real-time visible light communications prototype with data rate adaptation based on illumination conditions and speeds up to 500 Mb/s has been shown in [11]. It was totally based on commercially available low-cost technology and integrated both illumination and rapid wireless data transfers under highly realistic settings [12]. The speed-optimized, large-area CMOS compatible P+/N-well/P-sub and N-well/P-sub APDs, as well as their modelling and tests, were presented [13]. In the visible wavelength region, the P+/N-well APD was shown to have extremely low excess-noise factor values. High-speed operation, low-voltage biassing, and cheap cost are all advantages of the reported devices [14]. VLC stands out among the various options offered to supplement the present wireless network architecture owing to the significant benefits it offers. Free spectrum, high frequencies, infrastructure availability, and LED light bulbs are some of the benefits that bring attention to visible light [15]. However, several barriers remain in the way of commercialization of VLC-based technology and applications. Some of these issues are flickering, dimming control, uplink, and interference [16].

3. Methodology

The intended VLC system without taking external noise into account is shown in Figure 1 and Figure 2. Quasi random signal sequence is used to generate the electrical transmitter data for the Mach-Zehnder modulator, and white LEDs are used to generate the optical signal.

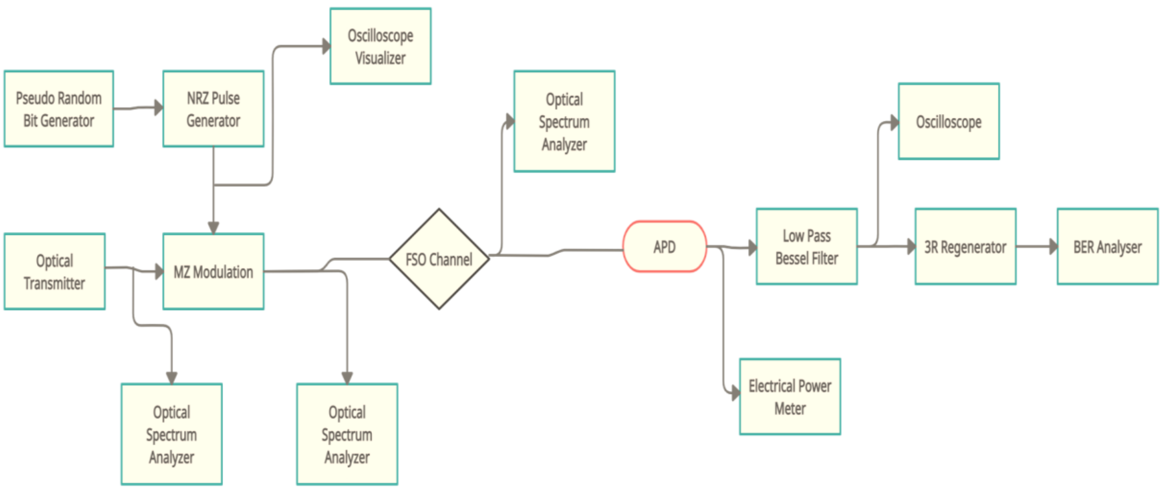

Figure 1. Block Diagram of VLC System

The Mach-Zehnder modulator controls the voltage level of an optical signal. Furthermore, the free space optics pass the modulated output from the Mach-Zehnder modulator into the receiver. An optical spectrum analyser and an optical power meter are used to examine the received signal.

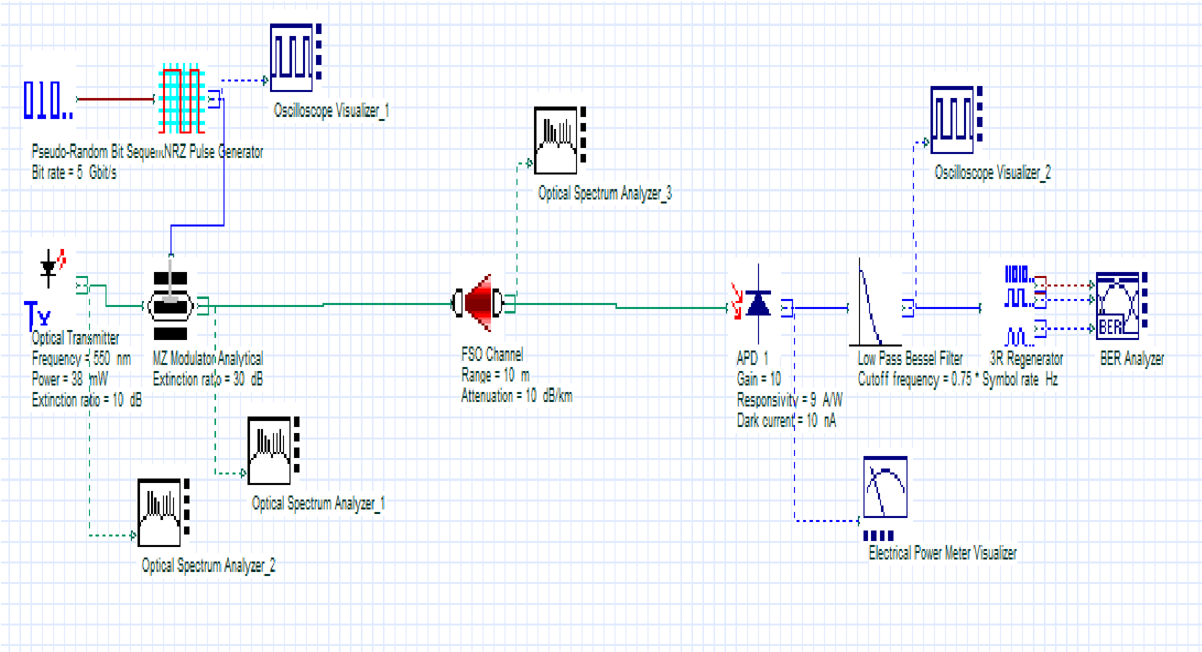

Figure 2. Circuit diagram of VLC System

Table 1. LED and APD Specifications

LED Specifications	
Centre Frequency	550 nm
LED colour	White
Extinction ratio	20
Power	30mW
Avalanche Photo Diode specifications	
Gain	10
Responsivity	9A/W
Dark Current	10nA

With the help of Optisystem16, a VLC structure is planned. The LED and APD specifications and Free Space Optical (FSO) specifications are shown in Table 1 and Table 2 respectively. The centre frequency of the LED is considered as 550 nm and color of LED as white with extinction ratio 20, and power of LED is taken as 30mW. The Avalanche photodiode's responsivity type is InGaAs, and the gain of APD is 10. In the planned VLC system, the dark current of the Avalanche photodiode is set at 10 nA.

Table 2. Free Space Optical (FSO) Channel Specifications

Attenuation	8db/m
Additional loss	1db
Transmitter Aperture Diameter	7cm
Receiver Aperture Diameter	7cm
Range	10-100nm

The signal loss is determined in the received signal, which is then converted back into an electrical signal using a photo detector. To estimate the noise signal, oscilloscope visualization is used to evaluate the Avalanche photo detector output. The electrical signal is passed through a low pass filter to reduce the noise level. The low noise signal is then transmitted to the 3R regenerator to recreate the original signal, and the signal is analysed in the simulation tool using an eye diagram and BER analyser.

4. Results and Discussion

Without considering external noise, the white LED in the designed VLC system operates at a frequency of 550nm. The designed VLC system is examined for different link distances from 10m to 100m at various data rates without taking external noise into account. The greatest quality factor at 10m is 18.481, and it may be transmitted up to 100 meters. The sent signal is transferred at 5Gbps, with signal quality deteriorating after 50m.

Table 3. Performance of VLC system

Max. Q Factor	19.73
Min. BER	4.9608e-087
Eye Height	0.000262723
Threshold	0.00028217

Table 3 depicts the eye diagram of a planned VLC system without taking into account the received signal's external noise, with a bit rate of 5Gbps at 5m. The table shows the projected VLC structure's maximum quality factor, minimum bit error rate, eye height, and eye diagram threshold. Without taking external noise into account, the maximum quality factor for the planned VLC system at 5Gbps over a 50m connection distance is 15.71.

The curve of the minimal log of BER from 10m to 100m is shown in Figure 3. This graph shows that the signal has a minimal BER up to 50m and a maximum BER over 50m, implying that the signal strength is reduced.

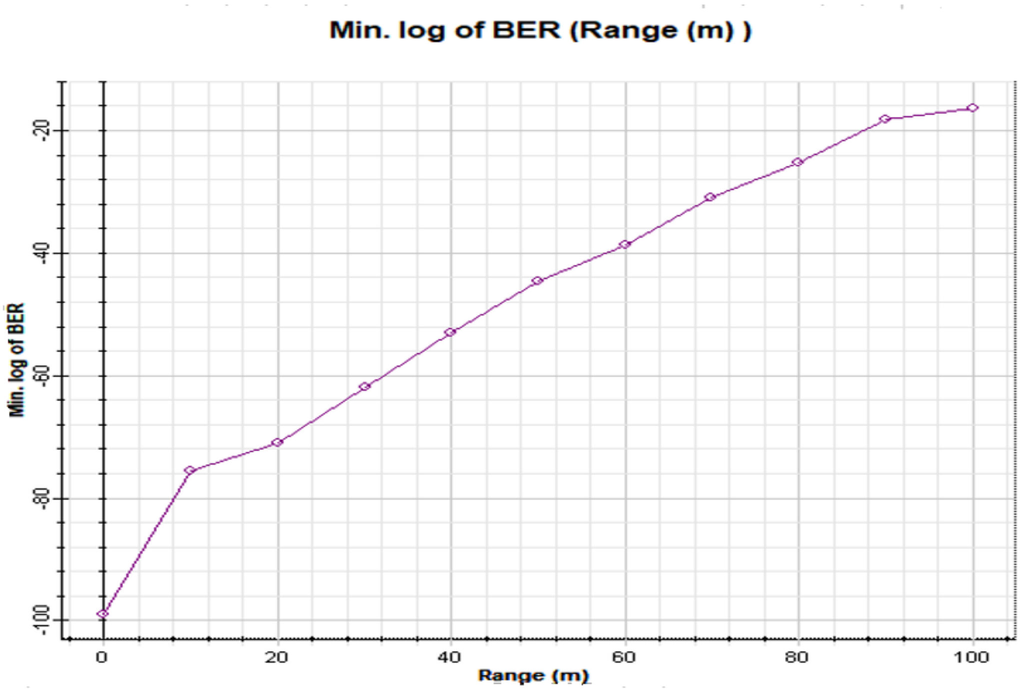

Figure 3. Minimal log of BER

5. Conclusion

The proposed work uses the Mach Zehnder modulator in opti-system software to analyse visible light communication with and without external noise. Without taking into account external noise, the suggested VLC system can support a link distance of 50m at 5Gb/s, but beyond that distance, the signal strength rapidly decreases. The VLC system, which takes environmental noise into account, can support link distances of up to 50m at 2Gb/s, although signal strength decreases after 50m. At 2Gb/s, the VLC system can only sustain up to 10m due to external noise. When comparing the performance of a VLC system without external noise to a VLC system with external noise, the VLC system without external noise performs better.

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