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Experimental Study on the Impact of Blue Filtering and Equalization in OOK-NRZ White LED Visible Light Communication Systems

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ABSTRACT

Visible Light Communication (VLC) offers a high-bandwidth, energy-efficient, and license-free medium for wireless data transmission using white LEDs. However, performance is limited by the phosphor's slow response and temperature sensitivity, which reduce modulation bandwidth and signal integrity. This study experimentally investigates improvements in a white LED-based VLC system using On-Off Keying Non-Return-to-Zero (OOK-NRZ) modulation through blue optical filtering and passive electronic equalization. The system was tested under data rates from 0.5–20 MHz and varying drive currents. A blue optical filter suppressed slow yellow phosphor components, while an R//C equalization circuit mitigated inter-symbol interference (ISI). Results show that blue filtering enhances high-frequency stability and extends modulation bandwidth, while equalization improves signal fidelity and eye diagram opening. Optimal performance was achieved at a driving current of 200 mA, balancing signal quality and thermal stability. These findings demonstrate that combining blue filtering and equalization provides an efficient, low-cost approach for improving data throughput and reliability in white LED-based VLC systems, enabling practical indoor communication and smart lighting applications.

Keywords:
Optical Filtering,
Signal Equalization,
Eye Diagram,
Thermal Stability,
Data Throughput.

INTRODUCTION

Visible Light Communication (VLC) has emerged as a promising complementary technology to traditional radio frequency (RF) systems, leveraging the visible light spectrum (400–700 nm) for wireless data transmission. Its advantages include high bandwidth, license-free spectrum, and dual use for illumination and communication (Haas et al., 2016; Gupta et al., 2023). White LEDs are preferred transmitters because of their energy efficiency and rapid adoption in modern lighting (Komine & Nakagawa, 2004).

However, phosphor-based white LEDs exhibit slow temporal response due to their yellow phosphor component, limiting modulation bandwidth and causing inter-symbol interference (ISI) at high data rates (Grubor et al., 2008; Harris & Clark, 2022). Moreover, performance degradation due to temperature variations impacts luminous efficiency and output stability (Yu et al., 2021; Martinez et al., 2023).

To overcome these challenges, optical blue filtering and equalization have been applied to enhance signal fidelity and spectral response (Tokgoz et al., 2019; Pham et al., 2023). On-Off Keying Non-Return-to-Zero (OOK-NRZ) modulation remains attractive for simplicity but requires compensation for LED bandwidth limitations. This paper presents an experimental study integrating blue filtering and a passive R//C equalizer to optimize VLC system performance. The results contribute to 6G and smart indoor network research (Smith et al., 2025; Powell & Scott, 2024), with relevance to developing infrastructures in Nigeria (Ibrahim et al., 2024).

MATERIALS AND METHODS

A Luxeon Star white LED (Philips Lumileds, Part No. LXHL-MW1B) served as the transmitter. A binary code of 20 Mbps was extracted from an established channel model (Ghassemlooy et al., 2019). The receiver used a photodiode (active area = 15 mm²) with a 30 mm focusing lens. Junction temperature was monitored using a Type K thermocouple and a 160×120 PX thermal imaging camera for non-contact thermal observation.

The received optical signal was amplified using a MAX 3664 Transimpedance Amplifier (gain = 6000 Ω) and displayed on a digital oscilloscope (input impedance = 50

Ω). A blue filter (center wavelength = 450 nm, bandwidth = 40 nm, 60% T) was installed before the photodetector. Data analysis, including signal plotting, BER, SNR, and eye diagrams, was conducted using Python.

Table 1: Specifications of Parameters Used in VLC Investigation

S/N	Parameters	Values
1	Luxeon LED Part number	LXHL-MW1B
2	Receiver concentration lens diameter	30 mm
3	Blue filter central wavelength and width	450nm, 40nm (60% through)
4	Photodetector (PIN) area	$15mm^2$
5	LED driver current (Low current)	300 mA (Low data rate in indoor application)
6	Preamplifier (Max 3664) TIA	6000 Ω
7	Equalizer capacitor (Ceramic X7R)	$15\ pF$
8	Equalizer 2 resistor (Surface-Mount Resistor)	10 KΩ
9	Load (Oscilloscope – input impedance)	50 Ω
10	Receiver input dynamic range	28 dB
11	LED beam angle	45°
12	Digital thermocouple	Typically type K
13	Thermal imaging camera	Thermal resolution 160x 120

Table 1 summarizes the experimental parameters. The selected driving current and optical filter bandwidth were optimized to balance system sensitivity and thermal stability.

Method

The LED intensity was modulated using OOK-NRZ coding. A binary stream (20 Mbps) was uploaded into an arbitrary waveform generator (AWG). Logic "1" turned the LED ON, and "0" turned it OFF. The optical signal traversed a 10 cm free-space channel to the photodiode. Two performance optimization strategies were applied:

i. Blue Filtering: The optical filter suppressed the slow yellow phosphor response, improving temporal response and system bandwidth.
ii. Equalization: A parallel resistor-capacitor (R//C) network was placed after the TIA to enhance high-frequency components and reduce ISI (Patel & Williams, 2024).

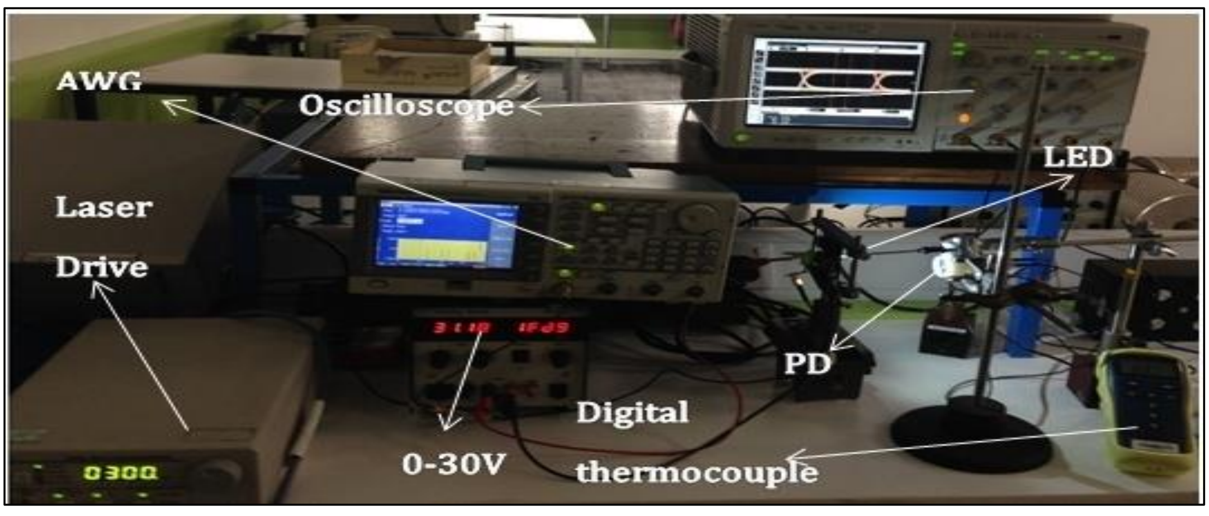

Plate 1: Experimental setup for the VLC system

RESULTS AND DISCUSSION

Impact of Blue Filtering on Frequency Response

The received signal strengths for unfiltered (white) and blue-filtered conditions were measured from 0.5–20 MHz.

Figure 1 presents the normalized signal response in dB versus frequency for both cases. Normalization was performed by dividing each voltage response by the maximum measured amplitude (V/Vmax) and converting to dB = 20 $\log_{10}$ (V/Vmax).

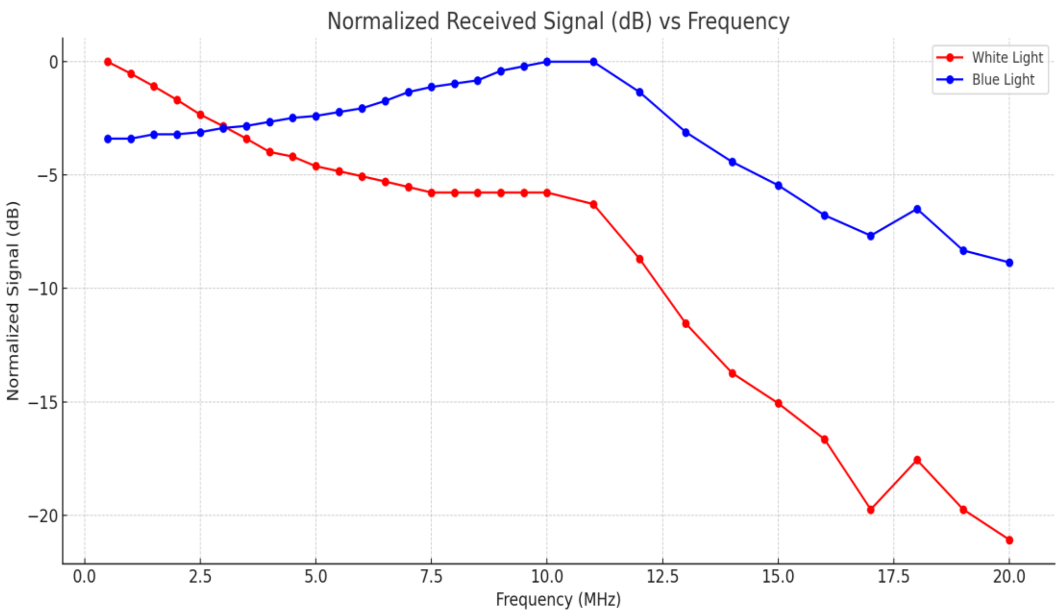

Figure 1: Normalized Received Signal (dB) vs. Frequency (MHz) for White and Blue Light

At 0.5 MHz, the white light response was 36.65 dB, reducing sharply to 15.56 dB at 20 MHz. The blue-filtered light started lower (≈19 dB) but remained stable up to 10 MHz and decreased gradually thereafter. The normalization shows that blue filtering sustains better high-frequency response by suppressing phosphor-induced delay. This supports similar observations in Minh et al. (2008) and Johnson et al. (2023).

Bandwidth and Power

Figure 2, illustrates the 3 dB bandwidth extension achieved through blue filtering, confirming its ability to expand modulation bandwidth. Figure 3 compares optical and electrical spectra, while Figure 4 shows power efficiency trends, indicating blue-filtered LEDs maintain stable power usage across frequencies — in agreement with Zhang et al. (2024).

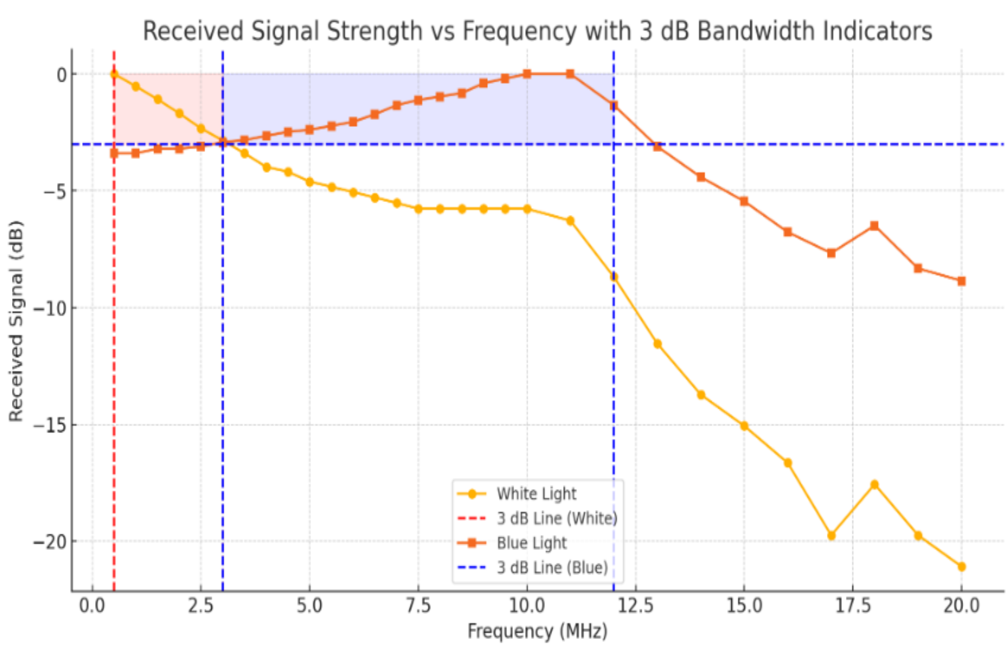

Figure 2: Received Signal Strength against frequency with 3dB Bandwidth indicator

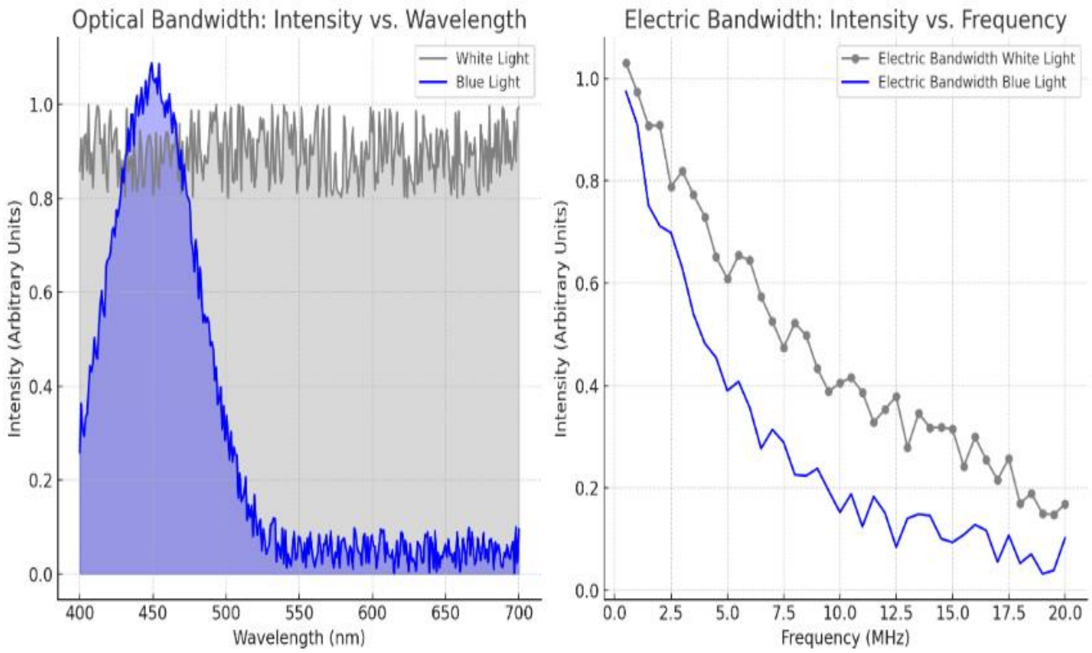

Figure 3: Simulation of optical and electrical bandwidths for white and blue light

The Figure 3 shows that the blue filtered LED maintains a higher and more stable electrical bandwidth compared to the unfiltered white LED. While the white LED's broad optical spectrum results in slower response and reduce modulation capability, the blue filtered light dominated by fast blue emission exhibits sharper transitions and improved high frequency performance.

Equalization Performance

Figure 4, compares two equalizers (EQ1 and EQ2). EQ2 produced a stronger and more stable signal, peaking at 34 mV around 10 MHz, whereas EQ1 peaked at 10 mV. The enhanced performance of EQ2 demonstrates effective ISI mitigation and synergy with blue filtering. Similar joint optimization effects were reported by Wang et al. (2022).

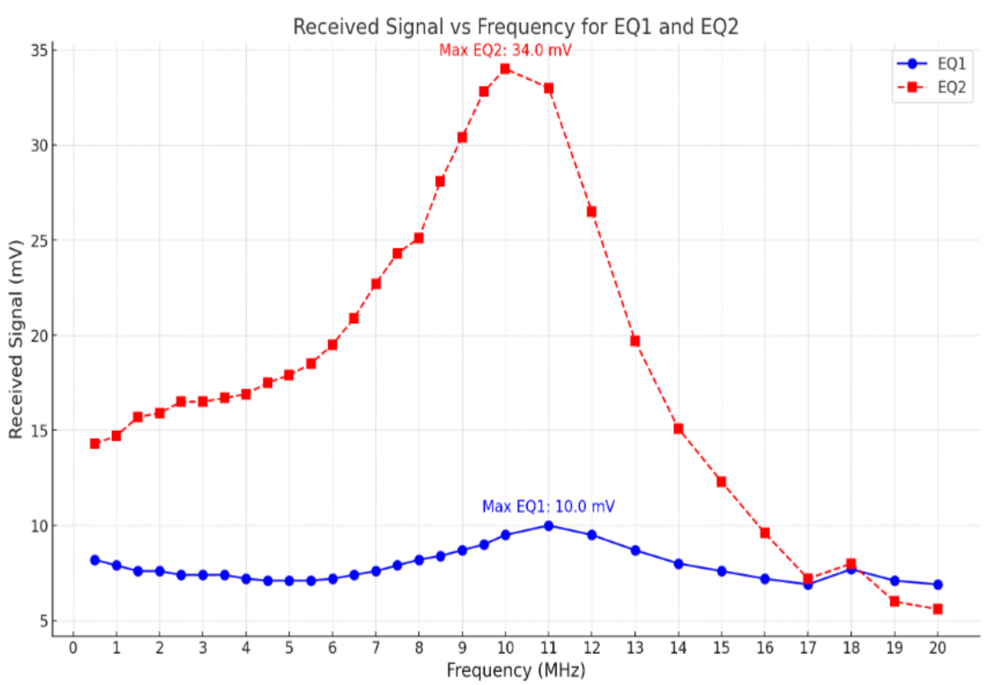

Figure 4: Received signal (mV) versus frequency (MHz) for EQ1 and EQ2

CONCLUSION

This study demonstrates that white LED VLC performance degrades at higher data rates due to phosphor delay and temperature effects. Blue filtering effectively mitigates high-frequency attenuation, while R//C equalization improves eye diagram quality and overall signal fidelity. An optimal driving current of 200 mA provided stable thermal and electrical balance. Combining blue filtering and equalization offers a practical, low-cost approach for improving data throughput and robustness in LED-based VLC. Future extensions will include adaptive equalization using machine learning and hybrid VLC/RF integration for 6G smart networks.

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