Multi-Gbps Visible Light Communication with High-Efficiency, Low-speckle Contrast White Laser Light

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Abstract. Multi-Gbps visible light communication is achieved using direct red-green-blue laser mixing in a novel packaging platform to produce white light with a low-speckle contrast of ≤ 5% and a high luminous efficacy of 150 lm/W_e.

Keywords: Visible Light Communication, Laser Diode Lighting, Multiple Scattering, Speckle Contrast, Direct Color-mixing.

1 Introduction

Global electricity consumption for lighting continues to increase, and this growth is not offset by the improvements in the efficacy of new lighting systems, which remain 30% below the requirements outlined in the International Energy Agency's 2030 Net-Zero Scenario [1]. Efficient white lighting from direct red-green-blue laser mixing has the potential to curb this offset. At the same time, wireless communication needs are increasing, with more devices connected to traditional routers than ever before, further congesting the already crowded radio-frequency spectrum while requiring faster download speeds [2]. Visible light communication (VLC), a technology that uses light to transmit data, is emerging as a solution for more rapid data rates without disturbing or being disturbed by other connected devices. To address both challenges, a multi-Gbps VLC system was developed which utilizes a novel transmitter with low-speckle contrast and high luminous efficacy, enabled by direct color-mixed white light.

2 Lighting System

To achieve high-efficiency, low-speckle contrast dispersed white light, a color-mixed laser diode (CM-LD) prototype was designed and characterized, consisting of RGB LDs, an acrylic mixing rod, two types of diffusers (rod diffuser and output diffuser), and a reflective cavity. Here, RGB laser beams are firstly coupled and guided in the mixing rod. The bulk scattering from the rod-bottom diffusers then redirects the light to the highly reflective interior surfaces of the cavity. The output diffuser allows further

S. Kurimura and T. Yagi (eds.), *Proceedings of Laser Display and Lighting Conference 2025*, Springer Proceedings in Physics 429,
https://doi.org/10.1007/978-981-96-9782-3_34

bulk scattering and forward transmission of the CM-LD white light [3]. With this compact, universal-packaging platform for direct color-mixing schemes, a low-speckle contrast of ≤ 5% and a high luminous efficacy of 150 lm/W_e were achieved. With future improvement of blue-laser-diode efficiency and development of yellow/amber/orange laser diodes, this universal white-laser package can potentially achieve a luminous efficacy > 275 lm/W_e in reference to the input electrical power, ~1.5x higher than state-of-the-art LED lighting and exceeding the target of 249 lm/W_e for 2035 [4]. In addition to its high efficacy, this solution demonstrated a 3 dB bandwidth of 1.3 GHz, indicating great potential for this laser-based white-lighting package in VLC.

3 Communication System

To demonstrate the communication capabilities of the color-mixed white-laser light, a VLC system was developed featuring the mixing package, an APD210-Si avalanche photodiode (APD), two ARM + FPGA development platforms, and two custom printed-circuit boards (PCBs), functioning as the transmitter and receiver, respectively. The first FPGA receives data via direct memory access (DMA) from a desktop computer, encodes it, and outputs it at a programmable data rate of up to 1.5 Gbps to the high-speed transceiver pins on the FPGA. The encoding scheme used here is 8b/10b, and as such, a line rate of 1.25 Gbps is required from the transmitter to achieve a data rate of 1 Gbps due to the two non-data bits in the encoding. The transmitter PCB receives this signal and uses it to modulate the red-laser-diode in the mixing package with on-off keying. The APD on the receiving end detects this optical signal and inputs it to the receiver PCB. The receiver PCB then converts the received signal into one decodable by the second FPGA. The second FPGA moves the decoded message to the processor on the same chip, where it is formatted into packets and delivered via an ethernet cable to a second computer. With this setup, the ability of the system to stream a live webcam video from one computer to another was demonstrated using a data rate of 1 Gbps and a distance of 1 meter between the lighting package and APD (Fig. 1 (a)).

When characterizing the system, AMD's LogiCORE™ IP Integrated Bit Error Ratio Tester (IBERT), which provides pattern generators and checkers implemented in FPGA logic, was employed [5]. The impact of data rate, distance, laser bias current, and angle of incidence on the bit error rate (BER) of the VLC system was investigated. In each test, over 40 billion bits generated from a 7-bit, pseudo-random binary sequence (PRBS-7) on the FPGA were transmitted and received. BERs below the forward-error-correction (FEC) threshold of 3.8×10^{-3} [6] were achieved for data rates up to 1.25 Gbps, free-space link distances up to 3.81 meters, and angles of incidence up to 30 degrees. With a distance of 1 meter between the lighting package and the APD, a BER of 2.4×10^{-11} was measured at a data rate of 1 Gbps, enabling high-performance streaming from a typical desk lamp height to a computer below. Fig.1 (b) and (c) show a portion of the data collected in this characterization effort.

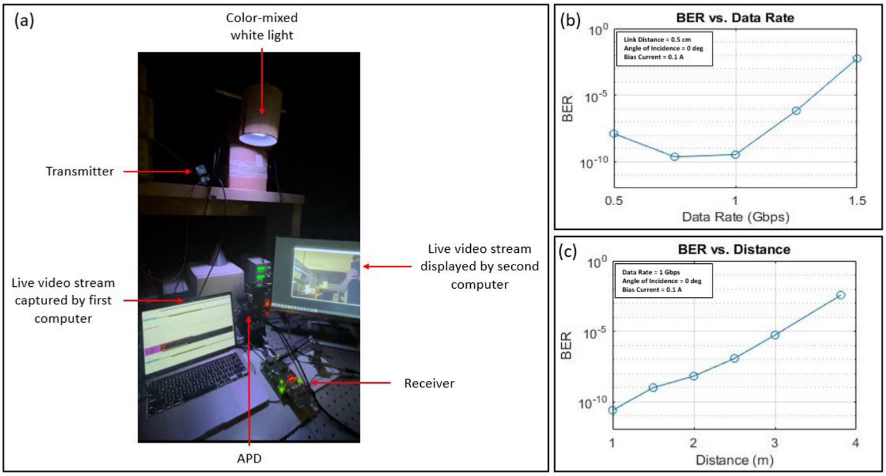

Fig. 1. (a) Live webcam video stream sent over free space by the color-mixed LD transmitter and displayed on a second, receiving computer. The impact of (b) data rate and (c) distance on bit error rate was determined when characterizing the communication system.

4 Conclusion

Using off-the-shelf electronics to modulate a luminaire consisting of RGB LDs, an acrylic mixing rod, two types of diffusers (rod diffuser and output diffuser), and a reflective cavity, quality Gbps visible light communication was achieved at distances up to 3.81 meters and receiver angles as large as 30 degrees. These results demonstrate that it is possible to have high-speed VLC with efficient, speckle-free (<5%) white light from multi-stage scattering and reflection, achieving bit error rates as low as 2.4×10^{-11} at a distance of 1 meter.

Acknowledgements. This work was supported by the National Science Foundation (CNS- 2308686) and the National Science Foundation Research Traineeship, Transformative Research and Graduate Education in Sensor Science, Technology and Innovation (DGE- 2125733). Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

Disclosure of Interests. The authors have no competing interests to declare that are relevant to the content of this article.

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