Performance evaluation of visible-light transceiver for peripheral interface

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Abstract. We examine the practicability of the visible-light communication (VLC) transceiver for bidirectional high-speed and short-range communications. A visible-light peripheral interface could be a novel approach, visualizing the veiled security feature of light by employing visible lights as communication media beyond its intended applications, such as illumination and display. The proposed VLC transceivers are implemented with edge-an emitting laser diode and a silicon photodiode, which is primarily designed to operate in a full duplex mode at 120 Mbit/s. The shielding method that is employed to reduce the light cross-coupling effect inside the VLC transceiver is proposed and experimentally investigated. The bit error rate performance of the proposed VLC transceiver is examined with respect to the transmission distance and the coverage. [DOI: 10.1117/1.3535588]

Subject terms: optical communications; optical devices; visible light communication.

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1 Introduction

Recently, the demands of high-speed and short-range communication systems have been increased to transfer the multimedia files between mobile equipment and home appliances. The desired features of the short-range connectivity for mobile equipments include low cost, low power consumption, high speed, high security, and easy connection. The existing candidates are either radio frequency (RF)–based techniques, such as Bluetooth and Ultra Wideband, or optical-based ones, such as infrared data association (IrDA) and visible-light communication (VLC). In comparison to the RF-based connectivity techniques, the optical one has unique advantages, including unregulated bandwidth of terahertz, intrinsic security, and simultaneous two-way transmission thanks to high directivity. The security feature has a great market potential from the perspective of end users, and intuitive interaction demands that the authenticity of communication partners must be easily verifiable by humans.[1]

However, there is no sensible difference between the RF-based connectivity and IrDA because both are physically invisible. VLC enables one to provide the veiled security feature of light by employing visible lights as communication media. Because users can actively align communication links by observing the visible beam spot or area, no one can interfere or obstruct without notice. In addition, the visible peripheral interface does not necessarily demand wide coverage, implying that its power consumption can be potentially lower than other invisible options.

Some research efforts on VLC applications have been made and reported previously, such as the indoor communications with room-illuminating light-emitting diodes[2] (LEDs) and the intelligent transport system with traffic signals.[3] In this letter, we investigated a wireless optical transceiver focusing on the high-speed and short-range visible communications with expectation to be used as a peripheral interface of hand-held devices such as mobile phones, notebook computers, digital cameras and so on. We demonstrated a practicability of VLC transceiver experimentally, which was designed to operate at 120 Mbit/s in the full duplex mode.

2 Proposed Visible-Light Communication Transceiver

For the compatibility with physical line speed of ultra fast infrared, the VLC bandwidth was set to 120 Mbit/s. The LEDs for ambient illumination typically have the modulation limit of ∼10 Mbit/s. The resonant-cavity LEDs (RCLEDs) for plastic fiber communications have sufficient modulation bandwidth but not have enough power to provide sufficient visibility. This finding leads us to use edge-emitting laser diodes (LDs) in visible wavelength, owing to the higher optical output power and the better visibility compared to RCLEDs. A diffuser was placed in front of the LD to comply with the eye safety regulation strictly applied to laser sources.[4]

The optical part of VLC transmitter consisted of three devices: an edge-emitting LD, a collimation lens, and a diffuser. The center wavelength of edge-emitting LD was ∼635 nm, and the full-width-half-maximum spectral width was ∼5 nm. The beam divergence of the red edge-emitting LD was also engineered to be <10 deg by placing a diffuser and collimation lens in front of the metal-can package. The beam spot was visible at the distance of up to 1.2 m in a typical office environment. The proposed VLC system uses on-off

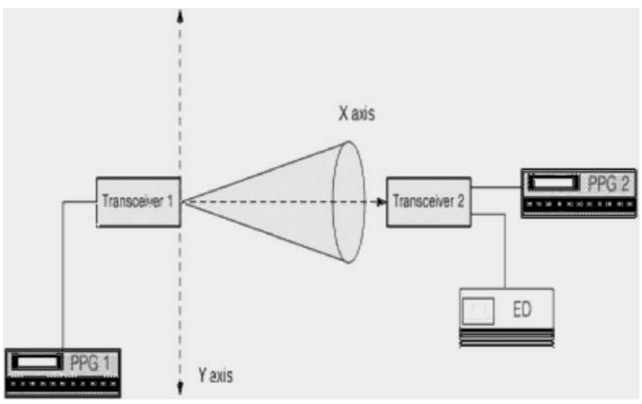

Fig. 1 Experimental setup for performance measurements.

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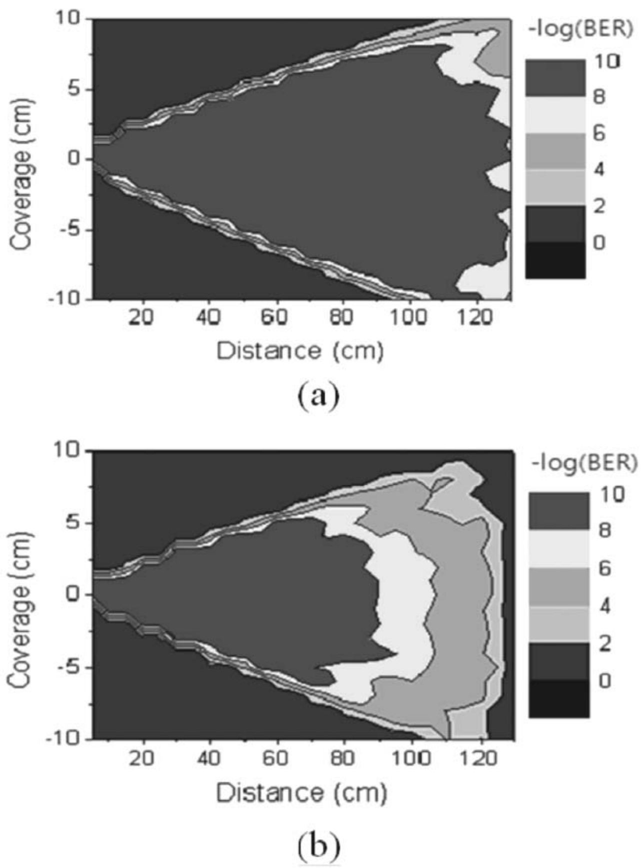

Fig. 2 BER performances of a transceiver at 120 megabite/s as a function of transmission distance and coverage (a) without and (b) with cross-coupling light.

keying (OOK) modulation. The measured optical power after a diffuser was ∼1.5 mW.

In the designed VLC receiver, a convex lens with 7-mm-diam was placed in front of a photodiode (PD) to concentrate incoming light. The ambient light is a noise source to the VLC optical receiver, which is mostly from indoor lighting. The power spectrum of the ambient light in the presence of fluorescent light extends up to 100 kHz.[5] An electrical high-pass filter with 300-kHz cutoff frequency was equipped right after a PD to reduce the influence of ambient light. No additional optical filter was used in the proposed VLC receiver.

3 Performance Measurements

Figure 1 is a schematic of the experimental setup to examine the designed VLC transceivers. VLC transceiver 1

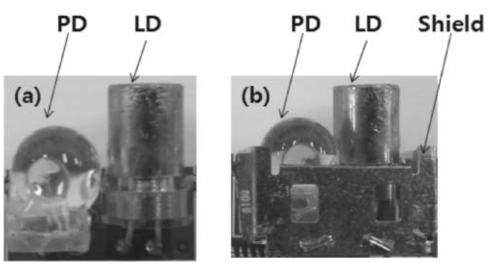

Fig. 3 Pictures of VLC transceivers (a) without and (b) with a shield.

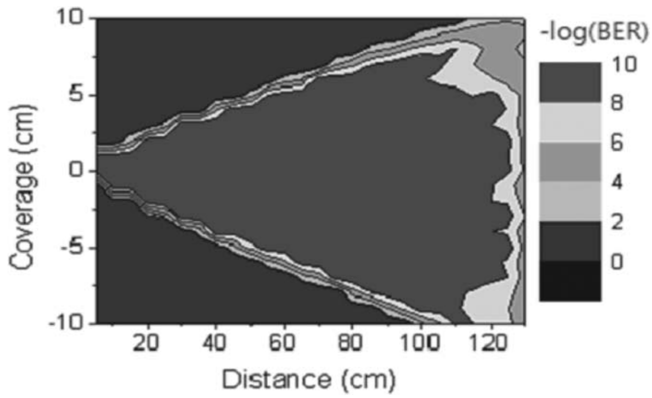

Fig. 4 BER performances of a transceiver with a shield in the presence of cross-coupling light.

was connected to a pulse pattern generator (PPG), PPG1, which generated a 2^7–1 pseudorandom binary sequence (PRBS) at 120 Mbit/s. Another transceiver, VLC transceiver 2, was connected to an error detector (ED), so that two VLC transceivers faced each other, as shown in Fig. 1. Transceiver 2 was moved along the X and Y axes while measuring the performance of the VLC transceiver. The bit error rates (BERs) were measured varying the transmission distance of X and the coverage range of Y. The distance and coverage are varied from 5 to 130 cm and from –10 to +10 cm, respectively.

We designed the VLC transmitters to have a beam profile that can provide uniform optical power distribution over the entire shining circle, so that the BERs at a distance were almost the same. It should be also noted that a clear boundary of the shining circle is observed, which is beneficial to clear visibility of the spot. The target BER is 10^{-8}, typically used in free-space short-range optical wireless communications, such as IrDA.[6] One of the major reasons that limits the performance of full duplex mode in an optical link is the cross coupling of light. There may be some challenging cases for optical link applications, where detrimental light scattering is serious and a receiver can be blinded by the light of its own transmitter. We carried out the measurements with and without the presence of a cross-coupling light. In Fig. 1, transceiver 2 was arranged to transmit a PRBS signal by turning on PPG2, which generated a cross-coupling light interference to transceiver 1 under investigation.

Figure 2 is the comparison of the BER performance of the proposed VLC transceivers without and with cross-coupling light. Figure 2(a) shows that the VLC system without cross-coupling light can provide BERs of $<10^{-8}$ at the distance of ∼110 cm, and within the coverage of ∼17.5 cm. However, Fig. 2(b) reveals that the distance and coverage for successful communications were reduced with cross-coupling light to ∼70 and ∼11 cm, respectively. However, note that the divergence angles for successful communications were not affected by the cross-coupling light.

A metal shield between LD and PD was utilized to block the scattered or reflected light as shown in Fig. 3(b). Figure 4 shows the BER performance improvement achieved by reducing the influence of cross-coupling light, extending the transmission distance and coverage range up to ∼100 and ∼15 cm, respectively.

4 Conclusions

We demonstrate the feasibility of the visible-light transceiver for the high-speed and short-range peripheral wireless interface applications of handheld devices. The proposed VLC design approach features "What-You-See-Is-What-You-Send" security by employing visible lights as communication media. This letter proved the practicability of a 120 Mbit/s VLC transceiver using an edge-emitting LD and a silicon PD based on the BER measurements. How the cross-coupling effect affects the performance of the proposed VLC transceiver was also examined, proving the necessity of the optical shield between LD and PD. The proposed transceiver provided BERs of $<10^{-8}$ at the distance of ∼70 cm without shield and at the distance of ∼100 cm with the shield in full duplex mode.

Acknowledgments

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