Investigation of Visible Light Communication Transceiver Performance for Short-Range Wireless Data Interfaces

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***Abstract* — We investigate the performance of a visible light communication (VLC) transceiver for bi-directional high-speed and short-range wireless data interfaces. The proposed VLC transceivers with optical antenna structure are implemented with edge-emitting laser diode and silicon photo diode, which is primarily designated 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 influence of the tilt degree between two transceivers without optical antenna and with optical antenna is investigated. Their bit error rate performance is examined experimentally with respect to the transmission distance, the coverage range and the tilt degree.**

Keywords - Visible light Communication; Free-space optical communications; optical wireless

I. INTRODUCTION

The various communication technologies have been advanced to process the immense amount of data information at a very high speed. Among them, recently, visible light communication (VLC) technology is attracting much attention as short range communication means of high speed. This technology uses light-emitting diodes (LEDs) emitting light with the wavelength interval of 380-700 nm to carry information. The VLC technology is a novel kind of optical wireless communication technology with high potentially which can play a supplementary role of wireless communication which is available at any time and any place. As supplementary system, VLC has many advantages compared to RF-based wireless communications [1]; (1) It can potentially use existing local power line infrastructure for wireless communication as a backbone, (2) The bandwidth which can use is virtually unlimited, (3) The security is very outstanding, that is, it is difficult for an intruder to pick up the signal from outside due to characteristic of light, (4) Transmitters and receivers using LEDs are cheap and there is no need for expensive radio frequency units, (5) Visible light radiations are free of any health concerns, (6) Furthermore, no interference with RF based systems exists, so that the use in airplanes or hospitals is uncritical. Currently, the VLC based on these advantages has been mainly investigated into various applications, such as ubiquitous communication system, intelligent transport communication system and illuminating light communication system [2], [3].

We have paid attention to use VLC technology in the high speed and short range communication as a peripheral interface of hand-held devices such as mobile phones, notebook computers, digital cameras and so on. Since users can actively align communication links by observing the visible beam spot, VLC transceiver does not necessarily demand a wide coverage, implying that its power consumption can be potentially lower than other invisible options. Another key issue to investigate feasibility of wireless optical connectivity technology is channel efficiency. Full duplex operation can significantly increase the efficiency of communication channel, but the self reflection of transceiver degrades the transmission performance. It is also difficult for users to align VLC transceivers to be faced each other for a long time due to the characteristic of portable equipment. Based on those observations, we investigated a wireless optical transceiver especially focusing on the high speed and short range visible communications. In this letter, we demonstrate a practicability of VLC transceiver experimentally, which was designed to operate at 120 Mbit/s in the full duplex mode with expectation to be used as a peripheral interface of hand-held devices.

II. THE PROPOSED VLC TRANSCEIVER

We tried to develop a VLC transceiver in a small package by gathering optical and electronic technologies and components currently available in a commercial market. The optical part of VLC transmitter consisted of three devices; a light source, collimation lens and a diffuser. For the compatibility with physical line speed of Ultra Fast Infrared and for competing with the matured RF-based connectivity technologies such as WiFi or UWB, the VLC bandwidth was set to 120 Mbit/s. It is known unfortunately that the LEDs for ambient artificial illumination or message signboard typically have the modulation limit of about 10 Mbit/s [4]. The resonant-cavity LEDs (RCLEDs) for plastic fiber communications have wide modulation bandwidth but do not have enough power to provide sufficient visibility. Edge emitted LDs in visible wavelength, on the other hand, have higher optical output power and show the better visibility compared to RCLEDs. In these regards, we adopted edge emitting LDs for the high speed short range visible light source. A diffuser was placed in front of LD to avoid the eye safety regulation strictly applied to laser sources [5]. The center wavelength of edge emitted LD was 635 nm and the full width half maximum spectral width was about 5 nm. The beam divergence of the red edge emitted LD was also engineered to be less than 10° 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 keying modulation. The measured optical power after a diffuser was about 1.5 mW.

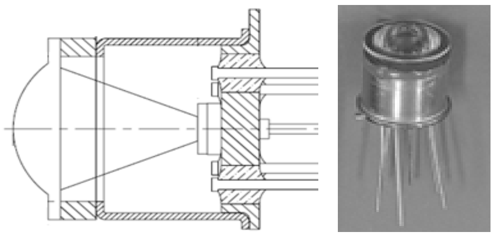


Figure 1. Drawing and picture of the designed optical antenna.

We investigated two types of VLC receiver, which utilize two methods of concentrating incoming light at the photo diode (PD). In the first method, a convex lens is to concentrate light which is available in the market. The size of the convex lens was chosen based on the beam divergence and the transmission distance, noting that a convex lens with bigger diameter has in general the smaller angle of field of view (FOV). In the designed VLC receiver, a convex lens with 7-mm diameter was used in front of PD. The second method uses an optical antenna as shown in Fig. 1, which was particularly designed for VLC receiver applications. Since optical antenna generally requires a more exact alignment, the optical antenna needs to be designed for a wider FOV. The measured FOV of our optical antenna is about ±10° . In addition, the surface of inside of the VLC receiver is coated for full reflection to help concentrating the incoming light. The ambient light is a noise source to the VLC optical receiver. The major source of ambient light inside building is indoor lightings. The power spectrum of the photo detector output in the presence of fluorescent light extends up to 100 kHz [6]. An electrical high-pass filter with 300 kHz cutoff-frequency was equipped right after a photo diode to reduce the influence of ambient light. No additional optical filter was used in the proposed VLC receiver.

III. THE PERFORMANCE EXAMINATIONS

Fig. 2 is a schematic of the experimental setup to examine the designed VLC transceivers. VLC transceiver 1 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, so that two VLC transceivers face each other as shown in Fig. 2. Transceiver 2 moved along X axis and Y axis while measuring the performance of the VLC transceiver. The bit error rates (BERs) were measured varying the transmission distance of X cm and the coverage range of Y cm. The distance and coverage are varied from 5 cm to 130 cm and from -10 cm to +10 cm, respectively.

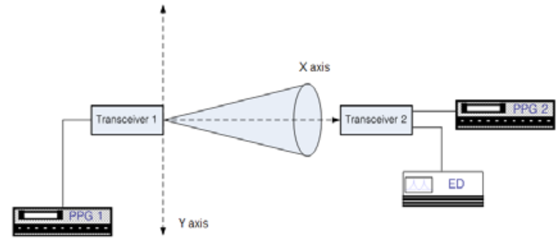
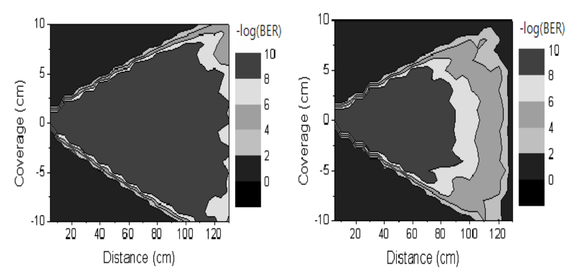


Figure 2. Experimental setup for performance measurements.

We designed the VLC transmitters to have the beam profile which can provide the uniform optical power distribution over the entire shining circle, so that the BERs at a distance were almost same within a coverage range. It should be also noted that a clear boundary of the shining circle is observed, which is beneficial to clear visibility of the spot. One of the major reasons that limit the usage of full duplex mode in optical link is the cross coupling of light. There may be some tricky cases for the 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 the cross coupling light. In Fig. 2, Transceiver 2 is arranged to transmit a PRBS signal by turning on PPG2, which generates a cross coupling light interference to Transceiver 1 under investigation.

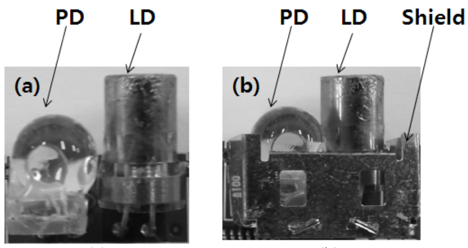


(a) (b)

Figure 3. The BER performance of a transceiver at 120 Mbit/s over the visible link as a function of transmission distance and coverage (a) without cross coupling light (b) with cross coupling light.

Fig. 3 is the comparison of the BER performance of the proposed VLC transceivers without and with cross coupling light. Fig. 3 (a) shows that VLC system without cross coupling light can provide BERs lower than 10^{-8} at the distance of about 110 cm and within the coverage of about 17.5 cm. But, Fig. 3(b) reveals that with cross coupling light the distance and the coverage for successful communications were reduced to about 70 cm and about 11 cm respectively. 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. 4(b).



(a) (b)

Figure 4. Pictures of VLC transceivers (a) without a shield (b) with a shield.

Fig. 5 shows the BER performance improvement achieved by reducing the influence of cross coupling light, extending the transmission distance and coverage range up to about 100 cm and about 15 cm respectively.

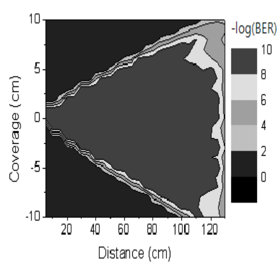
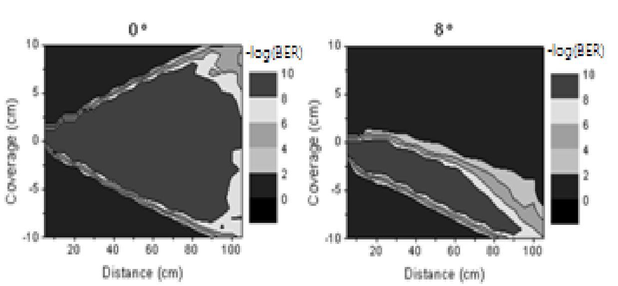
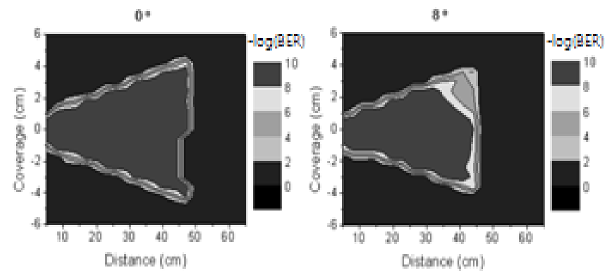


Figure 5. The BER performance of a transceiver with a shield in the presence of cross coupling light.

The tilting effect of the VLC transceiver was investigated because it is generally difficult for users to locate or to maintain the VLC transceivers facing each other exactly in many practical applications. While VLC transceiver 2 was tilted by 8° intentionally in Fig. 2, the BER performance was measured to obtain the Fig. 6. It was found out that the VLC transceiver equipped with an optical antenna experiences greater reduction in the transmission distance for successful communications with the tilting angle, but reveals better coverage range characteristics, in comparison with the VLC transceiver with a convex lens.



(a)



(b)

Figure 6. The BER performance of transceiver at 0 and 8 degree tilt (a) with a convex lens (b) with an optical antenna.

IV. Conclusion

We demonstrate the feasibility of the visible light transceiver for the high speed and short-range peripheral wireless interface applications of hand held devices. The proposed VLC design approach features What-You-See-Is-What-You-Send security by employing visible lights as communication media. This paper proved the practicability of a 120 Mbit/s VLC transceiver using an edge emitted LD and a silicon PD, by presenting the BER performance measurements with respect to the transmission distance and the coverage range. VLC system without cross coupling light can provide BERs lower than 10^{-8} at the distance of about 110 cm and within the coverage of about 17.5 cm. But, the distance and the coverage for successful communications were reduced with cross coupling light to about 70 cm and about 11 cm respectively. A metal shield between LD and PD reduced the influence of cross coupling light and extended the transmission distance and coverage range up to about 100 cm and about 15 cm respectively. It was found out that the VLC transceiver equipped with an optical antenna experiences greater reduction in the transmission distance to about 50 cm for successful communications, but reveals better coverage range characteristics with the tilting angle of 8 degree, in comparison with the VLC transceiver with a convex lens. It may need to be further investigated for improvement in the transmission distance and the coverage range.

Acknowledgments

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