Isolation Characteristics of Full-Duplex Visible Light Communication with Image Sensor

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***Abstract* - Isolation characteristics between white LED and image sensor in the transceiver for OOK were measured using two different LEDs to realize full-duplex and multiple-access visible light communication. No direct interference other than reflection from the receiver was observed and error free operations with BER of less than 10^{-4} were achieved for full-duplex and multiple-access visible light communication.**

***Index Terms* — Visible light communication, Image sensor, Full duplex, Isolation.**

1. Introduction

Multiple-access, two-way visible light communication with image sensor and LED array is experimentally verified using space division multiplexing (SDM) [1], [2]. Visible light can realize enough isolation for full-duplex communication utilizing the image sensor with high space resolution even though the LED with the same spectrum is used for communication in two ways. In this presentation, isolation characteristics between white LED and image sensor in a transceiver are measured for on-off keying (OOK) to realize full-duplex and multiple-access visible light communication using image sensor and white LEDs.

2. Isolation Characteristics in a Transceiver

Isolation characteristics between white LED and a CMOS image sensor in a station's (STA's) transceiver were measured as shown in Fig. 1. In the access point (AP), 4-element LED array is used for transmission. In the STA's transceiver, the LED is placed in parallel with the image sensor at a distance of 4, 5, and 6 centimeters away each other. The LED is moved backward and forward from the image sensor within ±5 centimeters to measure the interference from the LED to image sensor in the STA's transceiver.

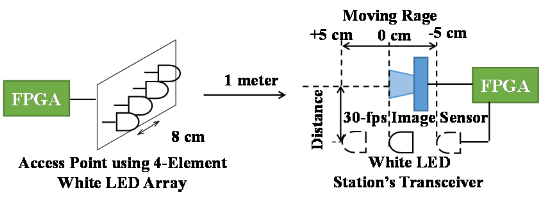


Fig. 1. Configuration of Transceiver for Isolation Measurements.

In the STA's transceiver, two kinds of LEDs are used for the measurement. One is a single LED with total luminous flux of 100 lumens. The other is 16-element LED array with total luminous flux of 26 lumens per element. Measured intensity pattern of each LED is shown in Fig.2. Half-power beam width (HPBW) of the single LED and 16-element LED array are 22 and 120 deg., respectively. On the other hand, field of view (FOV) of the image sensor is 68 deg. Captured image of each LED by the image sensor when the LED is placed 1 meter apart in front of the image sensor is shown in Fig. 3. HPBW of the single LED measured from the image is 21 deg. and coincides with that measured from the intensity pattern. On the other hand, HPBW of the 16-element LED array is 18 deg. and differs vastly from the correct one measured from the intensity pattern due to inferior wide-angle sensitivity and dynamic range of the image sensor.

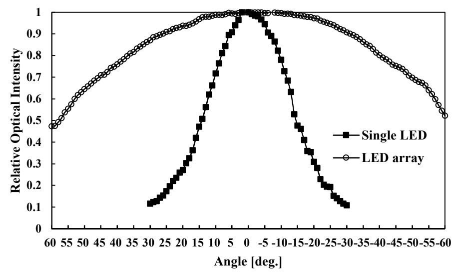
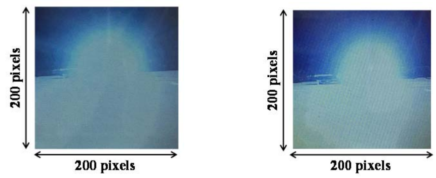
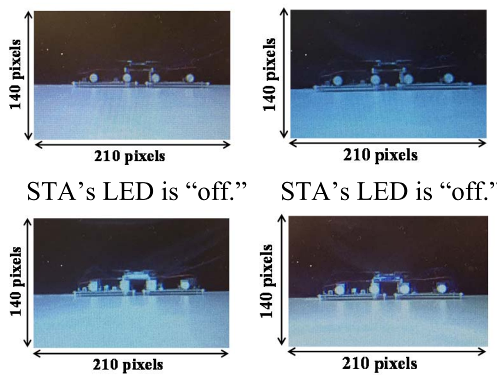


Fig. 2. Measured Intensity Pattern of Each LED.



(a) Single LED (b) 16-element LED Array
Fig. 3. Measured Image Pattern of Each LED.



(a) Single LED (b) 16-element LED Array
Fig. 4. Image of AP's 4-element LED Array Captured by STA's Image Sensor.

In order to measure the isolation characteristics from the LED to image sensor in the STA's transceiver (see Fig. 1), the STA's LED is modulated "on" and "off" and differences in image of the AP's LED array captured by the STA's image sensor were measured as shown in Fig. 4. While the AP's LED array is "off," the image of the AP's LED array looks slightly bright due to reflection of the STA's LED light from the AP's LED array when the STA's LED is "on" in both LEDs. However, since there are no differences in the background image of the AP's LED array captured by the STA's image sensor when the STA's LED is modulated "on" and "off" in both LEDs, the STA's LED light does not interfere directly with the receiving signals of STA's image sensor.

Next, bit error rates (BERs) between the AP's LED array and STA's image sensor were measured while the STA's LED is modulated "on" and "off" to measure the interference from the STA's LED to image sensor (see Fig. 1). 25-bps OOK signals are sent from the AP's LED array at a distance of 1 meter and received by the STA's image sensor while moving the STA's LED position back and forth. Error free operation with BER of less than 10^{-5} is obtained in both LED configurations as shown in Fig. 5. Since the optical intensity of the AP's LED array is much larger than the reflection of the STA's LED and no direct interference from the STA's LED affects to the STA's image sensor, full-duplex visible light communication can be realized using the same spectrum.

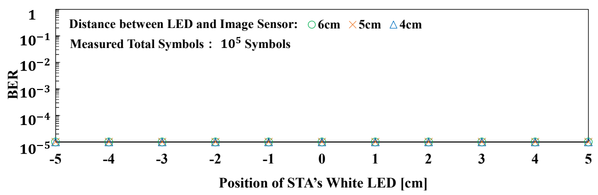


Fig. 5. BERs versus Position of Single LED or 16-element LED Array in the Station.

3. Full-Duplex and Multiple Access Visible Light Communication

Full-duplex and multiple access visible light communication was experimentally verified using the LED with HPBW of 22 deg. as shown in Fig. 6. The AP transceiver consists of 4-element LED array and image sensor. Two STA transceivers consisting of a single LED and image sensor were used for multiple access communication.

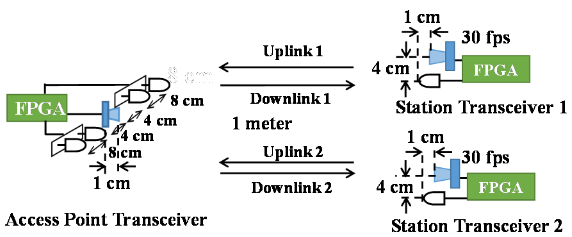


Fig. 6. Configuration of Full-Duplex Communication.

In every AP and STA transceivers, distance between the image sensor and the neighboring LED is 4 centimeters and the image sensor is placed 1 centimeter ahead of the LED as shown in Fig. 7. The AP's image sensor can receive two OOK signals from different STA's LED simultaneously and synchronize with each signal independently. On the other hand, the AP's LED array transmits two different OOK signals independently using different LEDs.

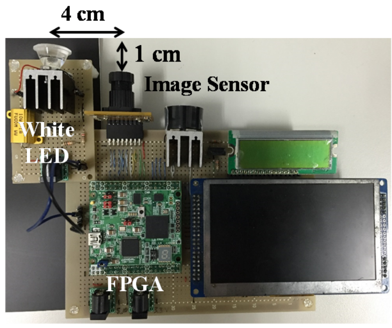


Fig. 7. Configuration of Transceiver.

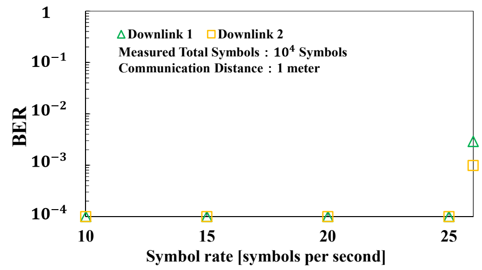


Fig. 8. BERs versus Symbol Rate.

BERs for full-duplex and multiple access visible light communication were measured as shown in Fig. 8. Error free operations with BER of less than 10^{-4} were achieved in the downlinks up to the symbol rate of 25 symbols per second without interference of uplink signals. The white LED with the same spectrum is used in two ways without interferences.

4. Conclusion

Isolation characteristics between white LED and image sensor in the transceiver were measured using a single LED and 16-element LED array with HPBW of 22 and 120 deg., respectively to realize full-duplex visible light communication. No direct interferences other than reflection from the receiver were observed and sufficient isolations for full-duplex communication were obtained in two different LED configurations. Furthermore, full-duplex and multiple-access visible light communication using the LED with same spectrum and HPBW of 22 deg. was experimentally verified and error free operations with BER of less than 10^{-4} were achieved for OOK.

References

[1] T. Kondo, R. Kitaoka, and W. Chujo, "Multiple-Access Capability of LED Visible Light Communication with Low-Frame-Rate CMOS Camera for Control and Data Transmission of Mobile Objects," in *Proc. IEEE/SICE International Symposium on System Integration*, 2015, Nagoya, Japan, pp. 678-683.

[2] T. Kondo, R. Kitaoka, and W. Chujo, "Multiple-access and two-way visible light communication with image sensor and LED array," in *Proc. 21st OptoElectronics and Communications Conference*, 2016, Niigata, Japan.