# Research on multi-color visible light communication system using RZ-4PAM signals with 67% duty cycle

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**Abstract.** In order to improve the transmission performance of visible light communication (VLC) system and user's demand for large-capacity and high-speed, one multi-color VLC scheme is proposed. This scheme uses red-green-blue light-emitting diode (RGB-LED) as the sender to transmit 4-ary pulse amplitude modulation (4PAM) signals with 67% return-to-zero (RZ). At the receiver, one optical bandpass filter is used for channel separation. By system simulation, we have measured the time-domain waveforms before and after transmission, eye diagrams of the three colors signals, and the bit error rate (BER) performance has been analyzed. The results show that at receiver power of -11dBm, the BER at back-to-back case is slightly lower than that of the signals transmitted in the 8m channel. Since 4PAM signals have higher spectral efficiency compared with the traditional binary signals, this scheme has potential application value in indoor broadband access system.

## 1 Introduction

Recently, broadband communication services have developed rapidly, especially the demand for indoor high-speed and large bandwidth access applications is increasing. At present, traditional radio frequency (RF) wireless communication has the problem of spectrum resource congestion. But the data transmission rate of visible light communication (VLC) system using LEDs can reach 1-10Gbit/s, and it can simultaneously achieve illumination and date transmission. Compared with traditional RF communication, it offers several advantages, such as high data transmission rate, users access security, large bandwidth and immunity to electromagnetic interference [1,2]. Therefore, VLC has become an important supplementary technology for 5th generation (5G) wireless communication application. However, the communication bandwidth of monochrome LED is not large enough [3]. By comparison, multi-color LEDs consisting of three, four and more colors can achieve the same luminescence effect as conventional white LEDs. Moreover, multi-color LEDs have larger transmission bandwidth, which use three colors of visible wavelengths to carry data information. As we know, three and four VLC systems are widely available. VLC

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technology with ultra-high capacity and high speed has become a research hotspot in the future wireless indoor communication [4,7].

Indoor VLC systems using advanced modulation techniques (such as discrete multi-tone (DMT) modulation and carrier-free amplitude and phase (CAP) modulation) can effectively improve the transmission performance, which have been widely studied in 5G and 6th generation (6G) wireless access networks [8,10]. As we know, the 4PAM signal can reduce the inter symbol interference (ISI) generated by multi-path effect. When 4PAM signals are combined with RZ codes with different duty cycles, it has better transceiver performance to meet the needs of different users [11].

We use RZ-4PAM modulation signals with 67% duty cycle to drive RGB-LED lights in VLC system in 8m indoor free space, and three visible wavelengths of red, green and blue are used to carry data information. We measured the time-domain waveforms and eye diagrams of RGB-LED signals before and after transmission through system simulation, and analysis transceiver and transmission characteristics of line-of-sight visible light signals.

## 2 Multi-color VLC system

Indoor VLC access system with 67% RZ-4PAM downstream signals is shown in Figure. 1. At the transmitter, the initial signals generated by one pseudo-random sequence generator (PRBS) pass through one RZ generator and one sine generator (SG) to generate the RZ signal with 67% duty cycle. Then one PAM sequence generator module and one M-ary pulse generator (MSG) module are used for generating the 4PAM signals. The 67% RZ-4PAM signals directly drive RGB-LED (the wavelengths are 650 nm, 550 nm and 450 nm respectively) to obtain three colors optical signals with different wavelengths. At the receiver, one Bessel optical filter (OBF) module is used to separate three optical signals and filter out the light carrying other information. The beams converge into the photodetector PIN to achieve optical-to-electrical conversion. Through the transimpedance amplifier (TIA) and automatic gain control (AGC), the signals are changed in a certain range, and the noise is filtered out by low-pass Bessel filter (LPF) to recover the original signals. At the end of the receiver is one BER tester for BER performance testing.

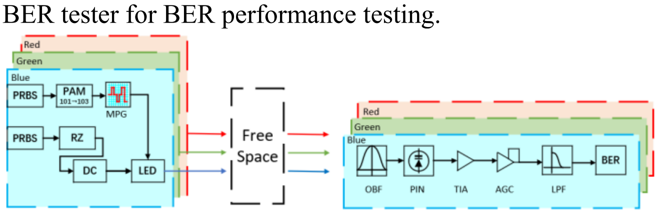
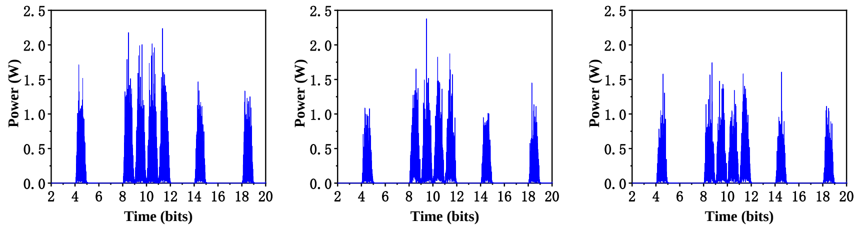



**Fig. 1.** Multi-Color Visible Light Communication System Using 67% RZ-4PAM signals.

## 3 Results

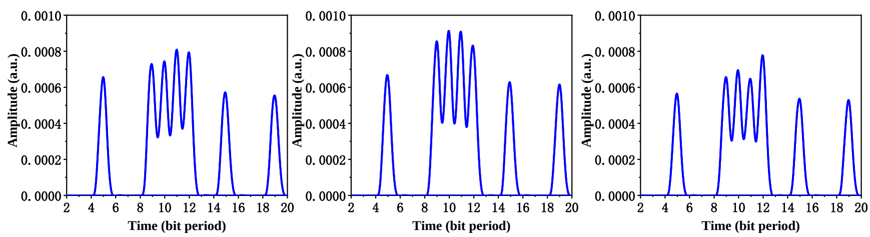
In the system, three 67% RZ-4PAM electrical signals are carried on RGB-LED lights, the output optical signals time-domain waveforms are shown in Figure. 2. The time-domain waveforms of the three electrical signals by the LPF filtering are shown in Figure. 3. It can be seen that the time-domain waveforms of the three signals have similar variations, but the signals amplitude changes at different wavelengths are different. Although the obtained electrical signals have a certain degree of distortion, it meets the transceiver requirements of signal quality.

Fig. 4 shows the eye diagrams measured at different working wavelengths (450 nm, 550 nm, 650 nm). By comparing the eye diagrams of the received signals under three working wavelengths, it is found that the eye openings of the three signals are different, which reflects the difference in the transmission performance of 67% RZ-4PAM signals at different working wavelengths. When the wavelength is 650 nm, the curve of BER and receiving power is shown in Figure. 5. The results show that with the increase of receiving power, the error rate decreases significantly. When the receiving power is -11dBm, the bit error rate is about $10^{-5}$. Compared with the back-to-back situation, when the receiver power is same, the bit error rate increases. After 8m transmission, indoor obstacles, dispersion and other factors cause the bit error rate performance degradation.



(a) 450nm wavelength (b) 550nm wavelength (c) 650nm wavelength

**Fig. 2.** Time-domain waveform diagrams of three optical signals.



(a) 450nm wavelength (b) 550nm wavelength (c) 650nm wavelength

**Fig. 3.** Receiver signals time-domain waveform diagrams.

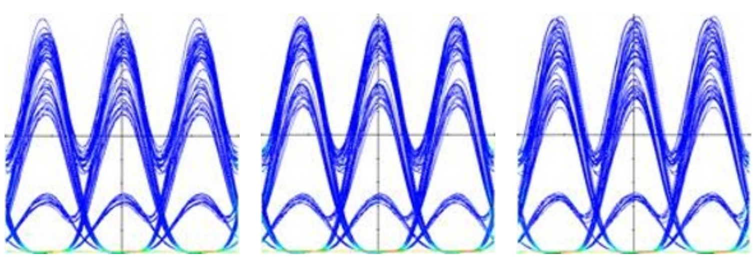

(a) 450nm wavelength (b) 550nm wavelength (c) 650nm wavelength

**Fig.4.** Eye diagrams measured at different working wavelengths.

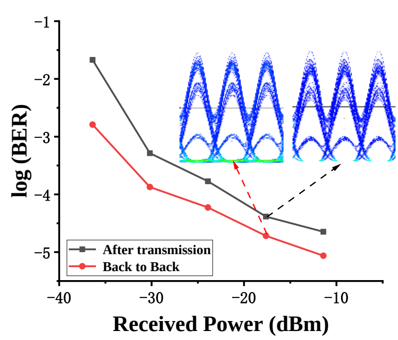



**Fig. 5.** BER performance of 650nm wavelength.

## 4 Conclusion

In this paper, we use 67% RZ-4PAM modulation to transmit RGB-LED three-channel optical signals in free space (8m indoor range). By system simulation, we have measured the time-domain waveforms before and after transmission, eye diagrams of the three colors signals, and the BER performance has been analyzed. The results show that the transmission performance of three signals is different. At receiver power of -11dBm, the BER at back-to-back case is slightly lower than that of the signals transmitted in the 8m channel. Since 4PAM signals have higher spectral efficiency compared with the traditional binary signals, this method has potential application value in indoor broadband access system.

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## References

1. D. C. O'Brien, L. Zeng, H. Le-Minh, G. Faulkner, J. W. Walewski and S. Randel, "Visible light communications: Challenges and possibilities," 19th IEEE International Symposium on Personal, IMRC, 1-5 (2008).
2. C. Singh, J. John, Y. N. Singh, et al. A review of indoor optical wireless systems [J]. IETE Tech. Review, **19**, 1-2, 3-17 (2002).
3. M. A. de Oliveira, E. S. Lima, M. S. P. Cunha, et al. RGB-based VLC system using 5G NR standard[J]. Optics Communications, 481: 126542 (2021).
4. H. Chun, S. Rajbhandari, G. Faulkner, et al. LED based wavelength division multiplexed 10 Gb/s visible light communications[J]. Lightw. Technol., **34**, 13, 3047–3052 (2016).
5. Y. Wang, L. Tao, X. Huang, J. Shi, and N. Chi, 8-Gb/s RGBY LED-based WDM VLC system employing high-order CAP modulation and hybrid post equalizer[J]. IEEE Photon. **7**, 6, 1–7(2015).
6. X. Zhu, F. Wang, M. Shi, N. Chi, J. Liu, and F. Jiang, “10.72 Gb/s Visible Light Communication System Based on Single Packaged RGBYC LED Utilizing QAM-DMT Modulation with Hardware Pre-Equalization.” Optical Fiber Communication Conference. Optical Society of America, M3K.3, (2018).
7. X. Liu, Z. Na, Y. Wang and T. S. Durrani, "Joint Resource Allocation for a Novel OFDM-Based Multicolor VLC Network," in *IEEE Networking Letters*, **3**, 3, 100-104 (2021).
8. N. Eiselt, et al., “Performance comparison of 112-Gb/s DMT, Nyquist PAM4, and partial-response PAM4 for future 5G ethernet-based fronthaul architecture,” J. Lightw. Technol., **36**, 10, 1807–1814 (2018).

9. X. Lu, M. Zhao, L. Qiao, and N. Chi, “Non-linear compensation of multi-CAP VLC system employing pre-distortion base on clustering of machine learning,” in Proc. Opt. Fiber Commun. Conf. Expo., 1–3 (2018).
10. F. Li, X. Li, J. Zhang, J. Y u, and Z. Cao, “Fiber-wireless-fiber link for DFT-spread OFDM signal transmission at W-band,” IEEE Photon. Technol. Lett., **27**, 12, 1273–1276 (2015).
11. F. P. Chen, Y. F. Shao, et al. "Study on RZ-4PAM downstream signals with duty cycles of 33% and 50% for optical access system application." Optoelectronics Letters, **13** (2017).