The BER Performance Comparison of MSK and GMSK Schemes for Short-Range Visible Light Communication

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Abstract—**In this paper, minimum shift keying (MSK) scheme and Gaussian minimum shift keying (GMSK) scheme used in Short-Range visible light communication(VLC) is presented. The light-emitting diode (LED) model in short-range VLC is introduced, the bit error rate (BER) performance of MSK is compared with GMSK by Monte Carlo simulations and experiments. The results are shown and MSK has the better BER performance than GMSK is verified.**

Keywords-light-emitting diode (LED); short-range visible light communication (VLC); minimum shift keying (MSK); gaussian minimum shift keying (GMSK)

I. INTRODUCTION

In recent years, with the rapid development of LED, VLC is also concerned by more and more people. For illumination, LED has the advantages of high brightness, small size, green, low power consumption and long life. For communication, VLC has the advantages of high bandwidth, high transmission rate, no electromagnetic radiation, high security and do not occupy the radio frequency spectrum and so on. In addition to the advantages mentioned, LED also has the characteristics of nonlinear modulation that caused by U-I nonlinearity [1]. In VLC, the signal after LED would be clipped due to the LED has different voltage to current conversion value.

Visible light communication adopts intensity modulation/direct detection (IM/DD), modulating the intensity of LEDs with analog signals can leads to significant signal degradation due to LED nonlinearity [2]. Both MSK and GMSK are constant envelope modulation, that is a kind of modulation technology that is suitable for nonlinear devices. Constant envelope modulation is divided into phase-continuous constant envelope modulation and phase-discontinuous constant envelope modulation, MSK and GMSK belong to latter. MSK can achieve truly constant amplitude with continue phase changes, MSK can be viewed as continuous-phase frequency shift keying (CPFSK) with modulation index h=0.5 [3], and GMSK signal generated by adding a Gaussian low pass filter in MSK baseband signal. Both MSK signal and GMSK signal have the characteristics of constant envelope, spectral compactness and continuous phase and so on.

In [4], under the data rate of 10Gb/s, the performance of MSK scheme in uplink space optical communication system is analyzed in detail. In optical fiber communication system, the optical MSK signal generation、detection and property is discussed in [3] and [5]. In [6], the bit error rate performance of MSK and GMSK in the AWGN channel is discussed. In this paper, MSK scheme and GMSK scheme used in short-range visible light communication is presented, and their bit error rate performance is compared by Monte Carlo simulation and experiments. In the simulation, the effect of LED nonlinearity to BER performance is considered, and shows the Rapps LED model we used in simulation. In the experiments, we transmit MSK signal and GMSK signal in 1Mb/s in the short-range visible light communication system, calculate the bit error rate by offline processing and show the results.

In section II, MSK and GMSK is introduced, the expression of MSK signal，Gaussian low pass filter and the signal of rectangular pulse after Gaussian low pass filter is given. Section III introduces the Rapps model and shows the specific model used in the simulation. In the section IV, the BER performance of MSK and GMSK in short-range indoor VLC is simulated by Monte Carlo simulation, MSK has the better BER performance and the BER performance of GMSK will become worse with time width product BT_s decreasing is verified. Section V introduces the experiment system and verifies that MSK has the better BER performance in 1Mb/s than GMSK for short-range VLC by experiments. The section VI concludes this paper.

II. MSK AND GMSK

MSK is developed from Frequency Shift Keying (FSK). MSK signal can be viewed as composed of two binary orthogonal 2FSK signal and MSK signal can modulated by I-Q modulation. What’s more, MSK signal has better envelope property, higher bandwidth efficiency than FSK signal and continuous phase (phase just changes $\pi/2$ every symbol period). In visible light communication, MSK signal have to add a suitable direct current (DC) bias because of LED has a turn-on voltage. So, the MSK signal can be given as:

$$\mathrm{s(t)} = \gamma + \mathrm{A}\cos(2\pi\left(f_c + \frac{b_k(t)}{4T_s}\right)\mathrm{t} + \varphi_k) \tag{1}$$

where, b_k is k-th biplor symbol and $b_k = +1$ when k-th input symbol $a_k = 1$, $b_k = -1$ when k-th input symbol $a_k = 0$. T_s is symbol period, f_c is carrier frequency, φ_k is k-th b symbol’ initial phase, A is amplitude of MSK signal, γ is direct current bias.

Like MSK signal, GMSK signal also has the characteristics of envelope constant, phase continuous and out-of-band power spectral density (PSD) drop quickly. The difference of the modulation of GMSK and MSK is that

GMSK' baseband rectangular pulse signal need pass a Gaussian low pass filter. As we know, rectangular pulse has a lot of out-of-band radiation and Gaussian low pass filter can filtering some high-frequency components, so the baseband rectangular pulse after Gaussian low pass filter has less out-of-band radiation and GMSK signal has more compact spectrum and less inter symbol interference (ISI) compared with MSK signal. The signal shaping performance of Gaussian low pass filter is determined by time width product $\mathrm{BT_s}$, B is filter's 3dB bandwidth and $\mathrm{T_s}$ is symbol period. $\mathrm{BT_s} = \mathrm{i}$, means filter's 3dB bandwidth is i times of symbol rate, in this paper, $\mathrm{BT_s} = 0.15, 0.2, 0.3$. The Gaussian low pass filter, $\mathrm{h(t)}$, can be given by [7], [8]

$$h(t) = \frac{1}{\sqrt{2\pi\sigma^2}} \exp\left(-\frac{t^2}{2\sigma^2}\right) \qquad \sigma = \frac{T_S\sqrt{ln2}}{2\pi(BT_S)} \tag{2}$$

The signal that rectangular pulse after Gaussian low pass filter can be described by [5]

$$g_{GMSK}(t) = \frac{1}{2}(erf\left[\delta\left(\frac{t}{T_S}+0.5\right)\right] - erf[\delta(\frac{t}{T_S}-0.5])$$

$$\delta = \sqrt{2/ln2} \cdot \pi BT_S \tag{3}$$

and the error function $\mathrm{erf(x)} = 2/\sqrt{\pi}\int_0^x e^{-t^2}\mathrm{dt}$. The signal after Gaussian low pass filter $\mathrm{g_{GMSK}(t)}$ steeper and more similar to rectangle pulse with increasing of the value of $\mathrm{BT_s}$. In other words, when the value of $\mathrm{BT_s}$ equals infinity, GMSK signal is MSK signal. Further more, GMSK signal can acquires more compact spectrum with the increasing of the value of $\mathrm{BT_s}$, but that at the cost of increase of inter symbol interference.

III. RAPPS MODEL

LED not only can be used for lighting, but also can realize the function of data transmission, what's more, LED is the main source of nonlinearity for VLC. LED is the transmitter in VLC, electrical signal converted to light signal through LED, messages sent out by LED and light signal detected by photoelectric detector (PD). LED has a voltage threshold which is called turn-on voltage (TOV). If input voltage below the TOV, the current through LED is zero (LED considered in a cut-off region); if input voltage above the TOV, the current through LED nonlinearly increase with increasing of input voltage (LED considered in current conduction region) [3]. So, if we want to transmit messages in VLC system, a direct-current (DC) bias is must added to ensure the input electrical signal works in LED's current conduction region. The LED output light power $\mathrm{P_o}$ is proportional to drive current $\mathrm{I_{LED}}$, $\mathrm{P_o = RI_{LED}}$, R is electrical-to-optical(E/O) conversion constant.

In [3], the Rapps LED model is presented and the effect of the LED nonlinearity on the symbol error rate (SER) of optical orthogonal frequency-division-multiplexing (O-OFDM) is analyzed. The LED has the property of nonlinearity mainly because of emitted photons is not proportional to the injected current amplitude [9].

In radio frequency (RF) system, the main nonlinearity device is the power amplifier (PA) [10], and Rapps model is commonly used to analyze the nonlinear effects. In VLC system, we can use the LED model with linear increase describe the LED U-I nonlinearity, this model is proposed based on the Rapps model. The required LED model given by [2]

$$i_{LED}(v_{LED}) = \begin{cases} h(v_{LED}), & v_{LED} \geq \mathrm{TOV} \\ 0, & v_{LED} < TOV \end{cases} \tag{4}$$

where $i_{LED}(v_{LED})$ is current through the LED, v_{LED} is the voltage of LED, and

$$h(v_{LED}) = \frac{v_{LED}-TOV}{(1+\left(\frac{v_{LED}-TOV}{i_{max}}\right)^{2k})^{1/2k}} \tag{5}$$

where i_{max} is the maximum permissible current through the LED, k is knee factor, and TOV is LED's turn-on voltage. The value of the knee factor k determines whether the signal' upper peaks smoothly clipping or hard clipping through LED model. In this paper, we assume TOV = 1 V, i_{max} = 2 A, k=3, and the U-I curve shows in Fig. 1.

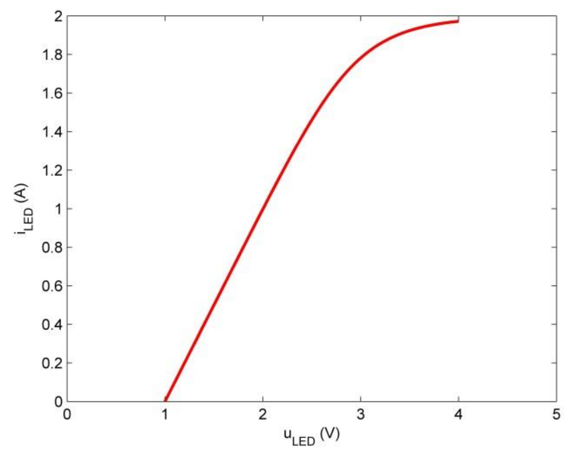


Figure 1. LED model.

IV. SIMULATION RESULTS

In this section, the bit error rate (BER) performance of MSK and GMSK in VLC is discussed and Monte Carlo simulation is carried out. The simulation is divided into two parts: consider LED' nonlinearity, not consider LED nonlinearity. In VLC, the additive white Gaussian noise (AWGN) mainly comes from thermal noise and ambient light noise. In order to fully reflect the effect of LED nonlinearity and consider the Rapps model, the parameters of MSK signal and GMSK signal shows in Table I.

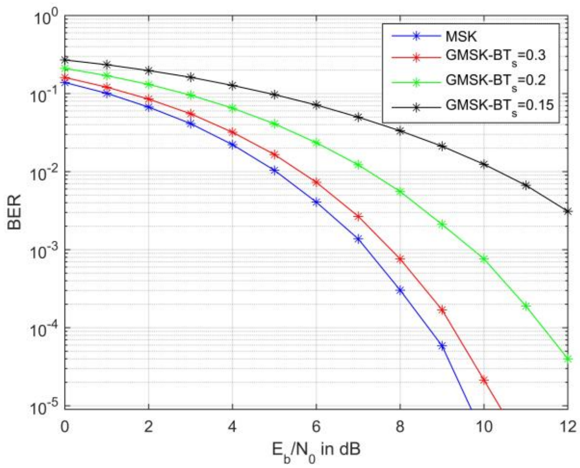
TABLE I. SIMULATION PARAMETERS.

Parameters	values
amplitude	0.8 V
DC bias	2 V

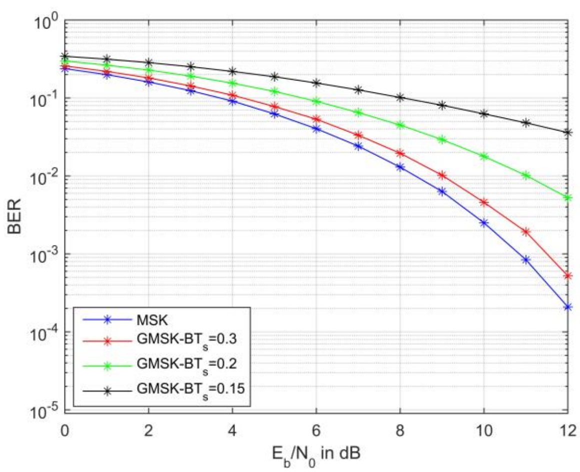
The amplitude of signal set to 0.8 V and the DC bias set to 2 V, so the input electrical signal works in LED's current conduction region that do not effected by cut-off region and the significant U-I nonlinearity region, which is the region of input voltage from 3V to 4V, as shown as Fig. 1.

Fig. 2 shows the results of the Monte Carlo simulation, MSK has better BER performance in VLC compared with

GMSK($BT_s = 0.15,0.2,0.3$), Fig. 2(a) is the result of BER performance not consider LED nonlinearity, Fig. 2(b) is the result of BER performance consider LED nonlinearity. The lower the value of time width product BT_s, the more serious the inter symbol interference (ISI). So when $BT_s = 0.3$, the BER performance is the best, and if $BT_s = 0.15$, the BER performance is the worst, when $BT_s = 0.2$, the BER performance is better than the $BT_s = 0.15$ and worse than $BT_s = 0.3$.



(a)



(b)

Figure 2. MSK and GMSK BER performance: (a) not consider LED nonlinearity; (b) consider LED nonlinearity

Furthermore, the nonlinear effect of LED to BER performance of MSK and GMSK can see clearly by compared Fig. 2(a) with Fig. 2(b). Example, the BER of MSK decreased -16.37dB, that of GMSK with $BT_s = 0.3,0.2,0.15$ decreased -14.26dB, -9.13dB and -4.95dB, when SNR is 8dB.

V. EXPERIMENTS

Bit error rate is an important index to measure the performance of modulation scheme, in this experiment, the BER performance of MSK is better than GMSK in 1Mb/s is verified for the short-range VLC system and shows the result of BER to different amplitudes of MSK signal and GMSK signal.

Fig. 3 shows the short-range VLC system, the transmitting end is composed of personal computer (PC), digital & analog conversion (D/A) card (SPECTRUM M2i.6031-Exp, max sampling rate: 125 MHz) which can convert digital signal to analog signal, power amplifier (PA), DC bias and LED (OSRAM LW W5SM-JYKY-JKQL-1), the receiving end is composed of avalanche photodiode (APD), analog & digital (A/D) card (SPECTRUM M2i.3015-Exp SN10243, max sampling rate: 160 MHz) which can convert analog signal to digital signal and PC. The LED's major features as follows:

- Typical luminous flux: 85 lm at 350 mA and up to 191 lm at 1A.
- Viewing angle: Lambertian Emitter (120°).
- Technology: ThinGaN.
- Optical efficiency: 99 lm/W at 100 mA.

For the short-range VLC system, in the transmitting end, the original digital signal is generated by matrix laboratory (MATLAB), digital signal converted to analog signal by D/A card and then modulated signal need get more power through PA to drive LED. It can be known from section II, we should add a DC bias in modulated signal before send out because of LED has a turn-on voltage. In the receiving end, the received optical signal converted into electrical signal by APD. Next, the electrical signal is converted to digital electrical signal and collected by the A/D card in PC. Finally, we can calculate the bit error rate by offline processing. The experimental scene is shown in Fig. 4.

In order to the experimental results more accuracy, we analyze the BER of MSK and GMSK under different signal amplitudes. The main parameters of experiment are shown in Table II.

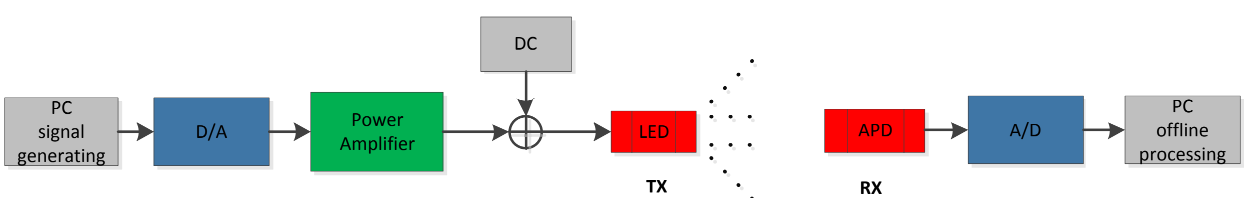


Figure 3. Indoor visible light communication system

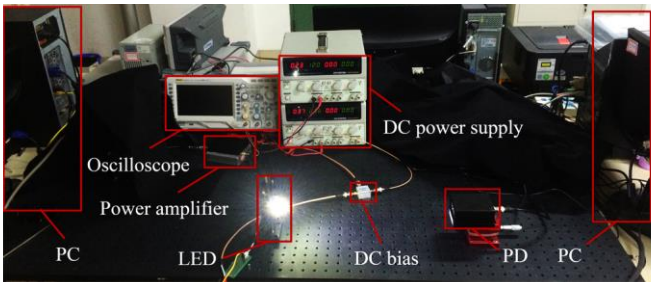


Figure 4. Short-range visible light communication experimental platform.

TABLE II. EXPERIMENTAL PARAMETERS.

Parameters	values
D/A(A/D) card sample rate	32M Hz
Communication distance	40 cm
Maximum amplitude	0.8 V
Minimum amplitude	0.08 V
DC bias	3.6 V
Bit rate	1 M bit/s
binary code number	1024000

Fig. 5 shows the experimental results, the BER performance of MSK and GMSK became better with the amplitude increasing because of the receiving end can acquire better SNR with the increasing of signal amplitude. In the same amplitude, the BER of MSK is lower than that of GMSK. So, MSK has better BER performance in short-range VLC compared with GMSK ($BT_s = 0.15,0.2,0.3$). Furthermore, the BER performance of GMSK is also become better with the increasing of the value of BT_s.

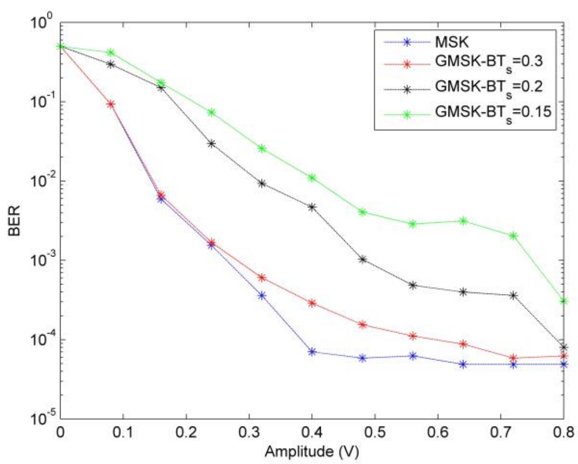


Figure 5. The BER of MSK and GMSK in different amplitudes.

VI. CONCLUSION

For short-range visible light communication, LED nonlinearity is an important factor that affects the performance of communication. We analyze the LED nonlinearity and compared the BER performance of MSK and GMSK. MSK has the better BER performance compared with GMSK whether LED nonlinearity is considered or not, and shows the results of Monte Carlo simulations. We implement the MSK and GMSK in the short-range visible light communication experimental platform, the experimental results show that MSK has better BER performance in short-range VLC compared with GMSK($BT_s = 0.15,0.2,0.3$) and the BER performance of GMSK is also become better with the increasing of the value of BT_s.

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