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Preliminary Study on LED VLC with Simple SR Receiver Using Schmitt Trigger

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Abstract

The present paper focuses on an application of Stochastic Resonance (SR) for an LED visible light communication (LED-VLC) receiver. SR is well-known as a phenomenon, which enhances the response by additive noise. We consider that a weak optical signal, which is distorted due to an influence of ambient light noise, can be detected by using SR system. This study makes a simple SR circuit for LED VLC and performs its circuit experiment for exploring the possibility and availability of the LED-VLC receiver using SR system.

1. Introduction

Visible light communication using light-emitting diode (LED VLC), which is a novel optical wireless communication technique, is focused in the field of communication systems [1]–[4]. One of great advantages of VLC is that this technique can not only provide light but also broadcast data. In addition, it can obtain high SNR compared to the conventional wireless and infrared communications.

One typical light receiving devices used in VLC is a photodiode (PD) [3][4]. Especially, PIN and avalanche PDs are well-used for the VLC receiver. This study focuses on the PIN PD since it is cheaper than the avalanche one. The PIN PD consists of three semiconductor regions: p-type, intrinsic and n-type. By doping the intrinsic semiconductor region between p-type and n-type ones, the PIN PD has the high-speed optical response property. However, the PIN PD is necessary to amplify the output since its output current is very weak. Moreover, the received optical signal is distorted due to an influence of ambient light noise such as the Sun.

As a method for solving this problem, we focus on Stochastic Resonance (SR) [5]–[9], which is well-known as a noise-enhanced phenomenon, for detecting the distorted (weak) signal. Figure 1 shows output signal-to-noise (SNR) properties of SR and the standard linear systems against the noise intensity. As one can see, the output SNR of the linear system decreases with increasing noise. On the other hand, that of SR system increases rapidly with increasing noise, passes through a peak and decreases gradually. Namely, SR system can detect the weak signal by the additive suitable noise. We focus this advantage and employ SR system for the VLC receiver using the PIN PD since it also might be able to detect the distorted optical signal.

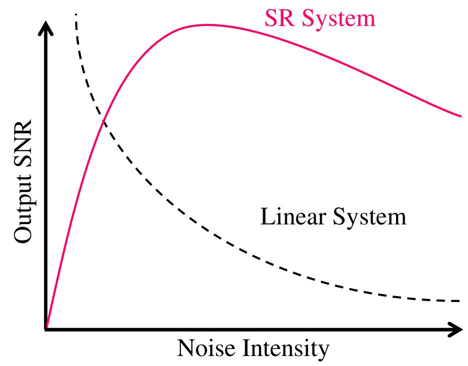

Figure 1: Output SNR property of SR system

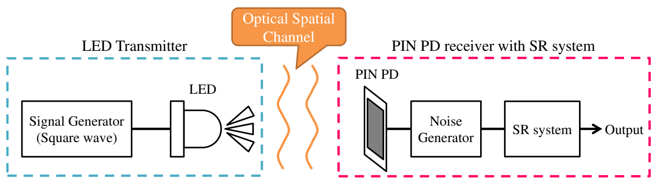

Figure 2: Block diagram of VLC system model with SR system

The present paper makes a simple SR circuit with the PIN photodiode and performs its circuit experiment for exploring the possibility and availability of the LED-VLC receiver using SR system. Specifically, we change a communication distance and the noise intensity, and qualitatively evaluate the output of the receiver by using an oscilloscope when the LED light (optical signal) is received.

2. System model

Figure 2 shows our experimental system model. This system consists of an LED transmitter, an optical spatial channel and a PIN PD receiver with SR system.

The LED transmitter consists of a signal generator and a single LED. The transmitter generates a square wave by the generator, and LED blinks depending on the square wave.

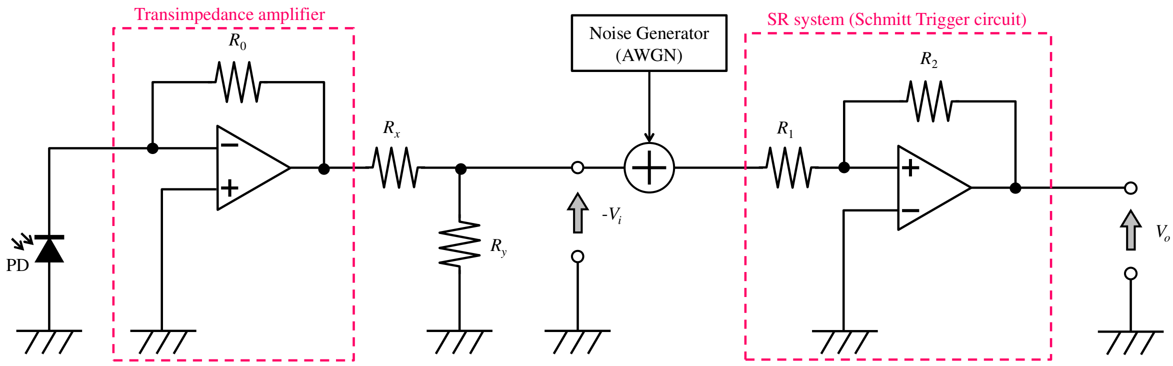

Figure 3: Simple PIN PD receiver with SR circuit

The receiver consists of the PIN PD, a transimpedance amplifier (current-to-voltage converter) unit, an internal noise generator and SR circuit, as shown in Fig. 3. The PIN PD receives an optical signal, which is transmitted from the LED transmitter, and the receiver converts into an electrical signal. However, due to the influence of the ambient light noise, the receiver cannot directly recognize the transmitted signal from the converted electrical signal. In order to simulate the ambient light noise in the experiment, we directly add a noise $n_{SR}(t)$, which generated from the internal noise generator, to the output voltage $s(t)$ of the PIN PD after the impedance adjustment . If the transmitted signal wave is observed at the output after the noise generator (i.e., $V_i = s(t) + n_{SR}(t)$), we can say that the transmitted signal is received at the receiver.

As the SR system in this study, we employ Schmitt trigger circuit [7][9], as shown in the right side of Fig. 3. As one can see, Schmitt trigger circuit consists of one operational amplifier (Op Amp) and two registers. Figure 4 shows its input-output characteristic. Here, V_i and V_o are its input and output voltages, respectively. Schmitt Trigger, known as a comparator which has hysteresis, has two outputs $\pm V_m$ and two thresholds $\pm\eta_{SR}$. In Fig. 4, η_{SR} is calculated by

$$\eta_{SR} = \frac{R_1}{R_2} V_m, \tag{1}$$

where V_m is the maximum voltage of Schmitt trigger. In the case of ideal Schmitt trigger, its output $r_s(t)$ ($= V_o$) is expressed as follows.

$$\begin{aligned} r_s(t) &= V_m \mathrm{sgn}(V_i - \eta_{SR}) \\ &= V_m \mathrm{sgn}(s(t) + n_{SR}(t) - \eta_{SR}). \end{aligned} \tag{2}$$

3. Experiments

In order to explore the possibility and availability of the LED-VLC receiver using SR system, we use above VLC system (shown in Figs. 2 and 3) and observe the optical signal

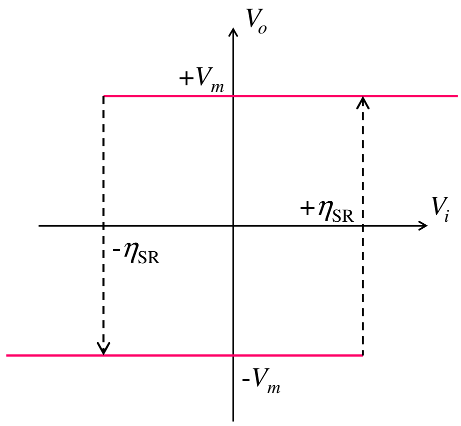

Figure 4: Characteristic of Schmitt trigger

detection property of the PIN PD receiver with Schmitt trigger circuit. Specifically, this study changes the communication distance (D) and the noise intensity, and qualitatively evaluates the output of Schmitt trigger circuit by using the oscilloscope when the LED light (optical signal) is received.

Table 1 shows experimental parameters. Each resistance value of Fig. 3 is as follows: R_0 = 10 kΩ, R_x = 64 kΩ, R_y = 2.2 kΩ, R_1 = 10 kΩ and R_2 = 10 MΩ. The threshold of Schmitt trigger (η_{SR}) is ±50 mV. The internal noise is zero-mean Gaussian noise which is assumed at the ambient light noise [10]. This study uses the additive white Gaussian noise (AWGN) for the internal noise. The transmitter and receiver are put face to face in a straight line, as shown in Fig. 2. Based on these conditions, we observe the output of Schmitt trigger circuit for D = 1 cm, 3 cm and 5 cm.

Figure 5 shows the output waveform when D = 1 cm (Upper part: Input signal V_i, Bottom part: Output of Schmitt trigger V_o). First, let us focus on Fig. 5(a). When the noise is not added to the input signal, we cannot observe the output of Schmitt trigger since the input signal without noise does

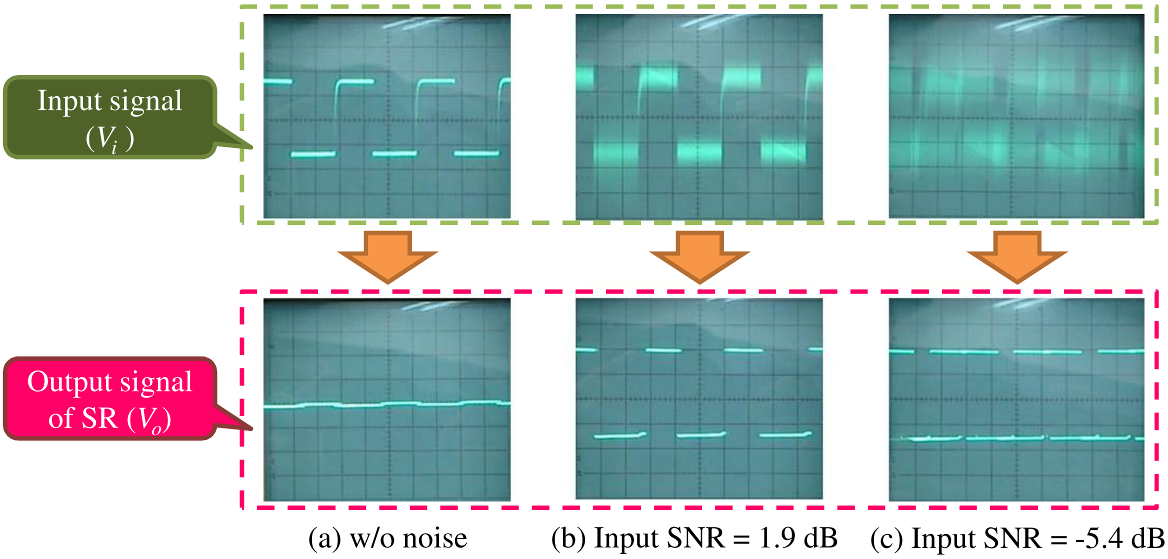

Figure 5: Output waveform of Schmitt trigger ($D = 1$ cm), (Upper part: Volts/Div=50 mV, Time/Div=1 msec, Bottom part: Volts/Div=2 V, Time/Div=1 msec)

Table 1: Experimental parameters

Frequency of square wave	600 Hz
Duty cycle of square wave	50%
Color of LED	White
Brightness of LED	18,000 mcd
Directivity of LED	15°
PIN PD	Si PIN PD S6775
Op Amp	LM7171
Internal noise	AWGN
Communication distance (D)	1 cm, 3 cm, 5 cm

not exceed the threshold η_{SR}. Next, we observe Fig. 5(b). As one can see, the signal component can be observed with increasing the noise intensity. In this experiment, we have observed the output of sharp square wave when the input SNR is 1.9 dB. However, the signal component is distorted with more increasing the noise, as shown in Fig. 5(c). These observed results indicate the characteristics of SR, as described in Sect. 1. Therefore, we can say that SR phenomenon is qualitatively confirmed in the LED VLC using SR system.

Figures 6 and 7 show the output waveforms for $D = 3$ cm and 5 cm, respectively. As is the case with $D = 1$ cm, we can observe SR phenomenon with increasing the noise intensity in both figures. Here, let us focus on Figs. 5(b), 6(b) and 7(b). We can confirm that the input SNR is different in each distance to achieve the sharp square wave. This is because that the LED light intensity, which is arrived at the PIN PD, reduces with increasing D, namely, the output current of the PIN PD becomes weak. Therefore, we can find that it is necessary to adjust the suitable noise intensity to exceed the threshold η_{SR} of SR along with increasing D.

In the case of the conventional communication system, its receiver generally becomes difficult to recover data from the distorted signal shown in the upper part of Fig. 5(b). In this experiment, it is confirmed that the receiver using SR system can obtain the signal component from the distorted signal, as shown in the bottom part of Fig. 5(b). Therefore, we can say that the possibility and availability of the LED-VLC receiver using SR system are indicated.

4. Conclusions

The present paper has made a simple SR circuit with the PIN PD, and has performed its circuit experiment for exploring the possibility and availability of the LED-VLC receiver using SR system. As experimental results, SR phenomenon has been qualitatively confirmed in the LED VLC using SR system. Moreover, we have found that it is necessary to adjust the suitable noise intensity to exceed the threshold of SR along with increasing the communication distance. These results have indicated the possibility and availability of the LED-VLC receiver using SR system. As a future work, we consider to quantitatively evaluate SR phenomenon of LED VLC based on the results of the present paper.

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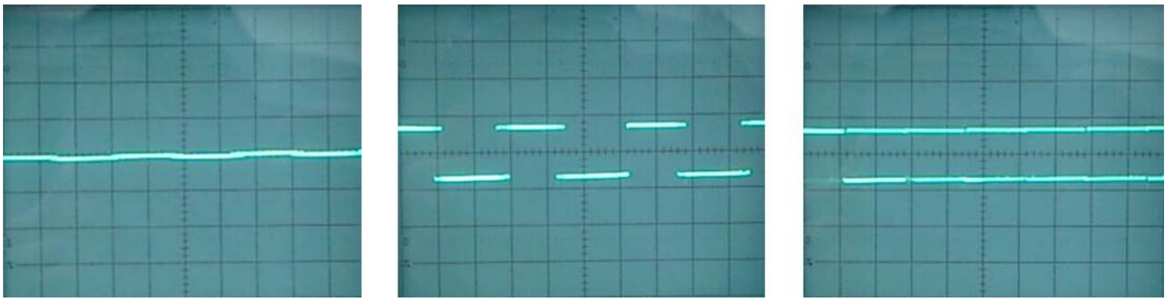
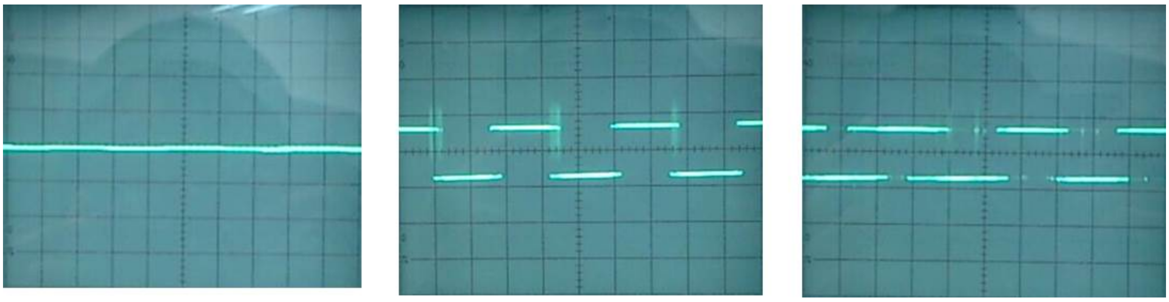


(a) w/o noise (b) Input SNR = -4.3 dB (c) Input SNR = -11.8 dB

Figure 6: Output waveform of Schmitt trigger ($D = 3$ cm) (Volts/Div=2 V, Time/Div=1 msec)



(a) w/o noise (b) Input SNR = -10.8 dB (c) Input SNR = -18.0 dB

Figure 7: Output waveform of Schmitt trigger ($D = 5$ cm) (Volts/Div=2 V, Time/Div=1 msec)

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