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Quantitatively Evaluation of Simple Stochastic Resonance Receiver Using Schmitt Trigger for LED Visible Light Communication

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Abstract—The present paper focuses on Stochastic Resontance (SR), which is well-known as a phenomenon that enhances the response by additive noise, and employs SR on an LED visible light communication (LED-VLC) receiver. We consider that VLC receiver with SR system can detect the transmitted signal component from the distorted optical signal due to an influence of ambient light noise. In order to quantitatively evaluate SR phenomenon of this system, we perform circuit experiments using the LED-VLC system using SR system and measures input/output characteristics of the receiver. In addition, we calculate an output power spectrum density (PSD) against the noise.

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]–[6]. One of great advantages of VLC is that this technique can not only provide light but also broadcast data. One typical light receiving devices used in VLC is a photodiode (PD) [5][6]. 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 have focused on Stochastic Resonance (SR) [7]–[14] for detecting the distorted (weak) signal. SR is a phenomenon that occurs in nonlinear systems whereby their responses are enhanced by additional noise. In general, noise has been treated as a nuisance in several research fields since it raises deterioration of the system performance. In contrast, SR actively exploits noise to achieve enhancement of the response. This characteristic is one of great advantages of SR.

We have focused on this advantage and have made a simple SR circuit with the PIN PD for exploring the possibility of the LED-VLC receiver using SR system in our previous study [14]. As results, we have confirmed SR phenomenon in the LED VLC using SR system. Thus the previous study have indicated the possibility of the LED-VLC receiver using SR system. However, we have only evaluated SR phenomenon qualitatively in the previous one. In order to evaluate SR phenomenon quantitatively, the present paper performs circuit experiments using the LED-VLC system using SR system and measures input/output characteristics of the receiver. In addition, we calculate an output power spectrum density (PSD) against the noise.

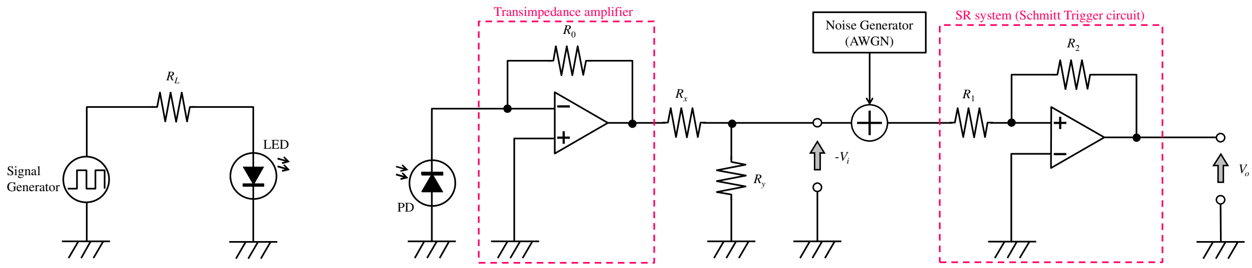
2. System model

Figure 1 shows an experimental circuit model. This circuit consists of a single LED transmitter and a PIN-PD receiver with SR system.

The LED transmitter consists of a signal generator, a registor R_L and a single LED, as shown in Fig. 1(a). The transmitter generates a square wave by the generator, and LED blinks depending on the square wave.

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. 1(b). The PIN PD receives an optical signal, which is transmitted from the LED transmitter, and the receiver converts into an electrical signal. However, the receiver cannot directly recognize the transmitted signal from the converted electrical signal due to the influence of the ambient light noise. In order to simulate the ambient light noise in the experiment, we directly add a noise $n_{SR}(t)$, which is generated from the internal noise generator, to the output voltage $s(t)$ of the PIN PD after the impedance adjustment.

As the SR system in this study, we employ Schmitt trigger circuit [11][13]. Schmitt trigger circuit consists of one operational amplifier (Op Amp) and two registers. Figure 2 shows its input-output characteristic. Here, V_i and V_o are



(a) Single LED Transmitter.

(b) PIN PD Receiver with Schmitt Trigger Circuit.

Figure 1: Simple PIN PD receiver with SR circuit

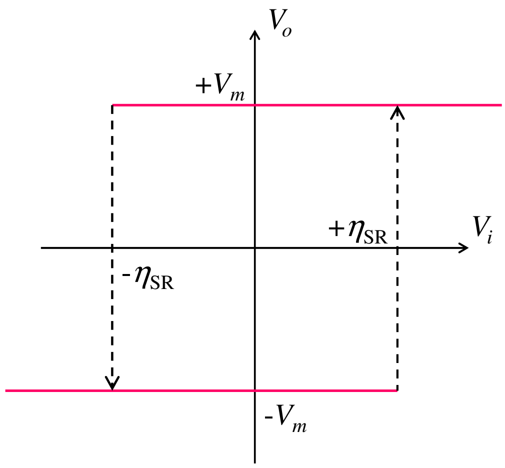


Figure 2: Characteristic of Schmitt trigger

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. 2, 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 and Quantitatively Evaluations

This section performs circuit experiments using above circuit and observe the optical signal detection property of the PIN-PD receiver with Schmitt trigger circuit. Especially, this study measures input/output characteristics of the PIN PD receiver with Schmitt trigger circuit and calculates an output PSD against the noise.

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)	3 cm

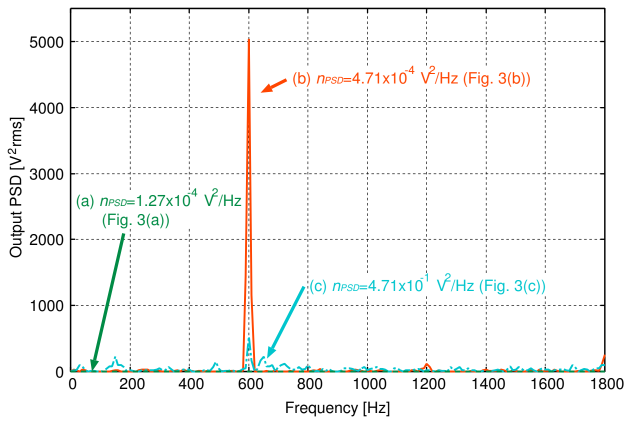
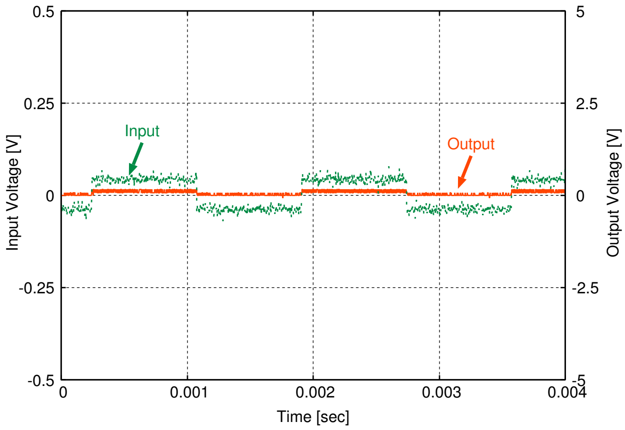
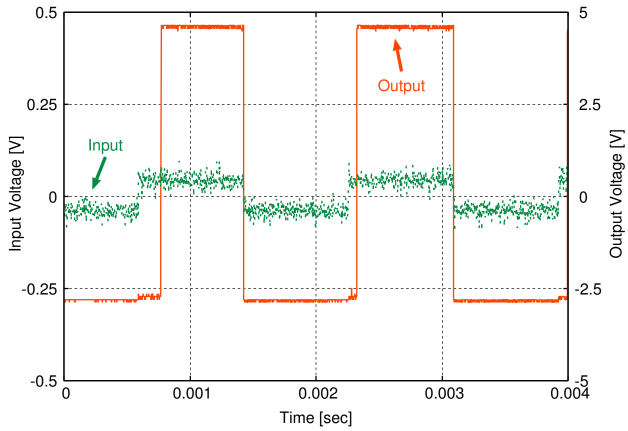


Figure 4: Output PSD Property of PIN-PD Receiver With Schmitt Trigger Circuit.

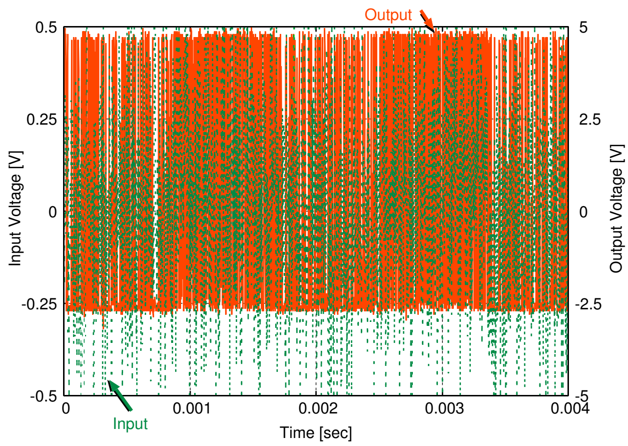
Table 1 shows experimental parameters. Each resistance value of Fig. 1 is as follows: R_L = 1 kΩ,R_0 = 10 kΩ, R_x = 64 kΩ, R_y = 2.2 kΩ, R_1 = 10 kΩ and R_2 = 10 MΩ. The threshold of Schmitt trigger (η_{SR}) is ±50 mV. The internal noise is zero-mean Gaussian noise which is assumed at the ambient light noise [15]. 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. Based on these conditions, we observe the output of Schmitt trigger circuit for the communication distance



(a) n_{PSD} = 1.27 × 10^{-4} V^2/Hz.



(b) n_{PSD} = 4.71 × 10^{-4} V^2/Hz.



(c) n_{PSD} = 1.10 × 10^{-1} V^2/Hz.

Figure 3: Input and Output Waveform of PIN-PD Receiver With Schmitt Trigger Circuit (D = 3 cm).

D = 3 cm.

Figure 3 shows input/output waveforms of the PIN-PD receiver with Schmitt trigger circuit for different noise intensities. As one can see, the output waveform can be observed with increasing the noise intensity. In this experiment, we have observed the output of sharp square wave when the input noise PSD (n_{PSD}) is 4.71 × 10^{-4} V^2/Hz. However, the output is distorted with more increasing the noise, as shown in Fig. 3(c).

Figure 4 shows output PSD properties of the receiver for different n_{PSD}. From this figure, we can observe the sharp PSD peak at 600 Hz when n_{PSD} = 4.71 × 10^{-4} V^2/Hz (Fig. 3(b)). However, we can not confirm the PSD peak when the noise is very week (n_{PSD} = 1.27 × 10^{-4} V^2/Hz, Fig. 3(a)). Although the PSD peak at 600 Hz is also observed when n_{PSD} = 1.10×10^{-1} V^2/Hz (Fig. 3(c)) , its peak is very small. In this experiment, LED blinks depending on the 600 Hz square wave with 50% duty, as shown in Tab. 1. Namely, the PIN-PD receiver with Schmitt trigger circuit can detect the transmitted signal component from the received optical signal by adjusting the suitable noise. These observed results indicate the characteristics of SR. Therefore, we can say that SR phenomenon is quantitatively confirmed in the LED VLC using SR system.

4. Conclusions

The present paper has performed circuit experiments using the LED-VLC system using SR system and has quantitatively evaluated its SR phenomenon has observed following features to quantitatively evaluate SR phenomenon: input/output characteristics of the receiver and output PSD properties against the noise. As experimental results, we have confirmed that the PIN-PD receiver with Schmitt trigger circuit can detect the transmitted signal component from the received optical signal by adjusting the suitable noise. Therefore, we conclude that SR phenomenon can be quantitatively confirmed in the LED VLC using SR system.

Acknowledgment

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