Circuit Experiment of Photodiode-type Visible Light Communication Using the Stochastic Resonance Generated by Interfering Light Noise

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2021 IEEE International Symposium on Circuits and Systems (ISCAS) | 978-1-7281-9201-7/20/$31.00 ©2021 IEEE | DOI: 10.1109/ISCAS51556.2021.9401452

***Abstract*—This study focuses on visible light communication (VLC) using a photodiode as a receiver. Accurate data transmission by this type of VLC is a challenge because the photodiode cannot detect weak light of subthreshold intensity owing to its insufficient light sensitivity. To overcome this problem, we employ a stochastic resonance, which is a nonlinear phenomenon in which the response characteristics of a system improve as its noise intensity increases, for the receiver of this VLC system. We also employ additive light-emitting diode light, which interferes in the photodiode as intentional noise. As an experimental result, the stochastic resonance was achieved by setting the parameters of the noise source appropriately, and we recovered the weak transmitting signal at the receiver.**

***Index Terms*—Visible light communication, Photodiode, Stochastic resonance, Interfering light noise**

I. Introduction

Visible light communication (VLC) is a type of optical wireless communication technology that uses light visible to the human eye [1]–[4]. A feature of this technology is that it can provide a communication capability as an additional value to devices that use visible light, such as lighting equipment and displays. Light-emitting diodes (LEDs) are generally used as the transmitting device, and the data are transmitted by changing the brightness of the LEDs. A photodiode (PD) and an image sensor (camera), which can detect LED light, are mainly used as a receiving device. This study focuses on a VLC system using a PD as the receiving device [5], [6]. For convenience, we refer to this system as PD-type VLC in this paper.

The PD is a type of semiconductor device that generates an electric current according to the light hitting the surface of the PD. Typical PDs include a PIN photodiode (PIN-PD) and an avalanche photodiode. They are characterized by their extremely fast response time. In other words, PD-type VLC is suitable for high-speed communication because PDs can easily detect LED light that blinks at high speed for data transmission. However, the data transmission by this system is not very accurate as the photodiode faces difficulties in detecting weak light of subthreshold intensity due to its light sensitivity. Thus, a method to detect a transmitting optical signal attenuated to the subthreshold level at the receiver is an important task.

To address this problem, we focused on the stochastic resonance phenomenon [7]–[11] and proposed some methods to apply it to communication technology [12]–[17]. Stochastic resonance is a type of nonlinear phenomenon in which the response characteristics of a system improve as its noise intensity increases. In general, noise is considered to be a hindrance in engineering and is actively removed using filtering and other methods. However, the stochastic resonance phenomenon takes a different approach and improves the response of the system by actively using noise. By using this phenomenon, we expect to develop a new communication system that can detect even weak signals that are buried in noise.

In this study, we incorporated a device that causes stochastic resonance into the receiver of a PD-type VLC system and try to detect a weak transmitting optical signal by performing a simple circuit experiment. Specifically, to detect the LED optical signal with attenuated intensity (desired signal) in the receiver, other LED lights that interfere with the desired signal are used as noise. In this paper, the light of these LEDs is referred to as interference signals. By varying the noise intensity by changing the number of interference signals and the pulse widths as these signals reach the PD of the receiver, a stochastic resonance phenomenon is generated, and the weak desired signal can be detected.

II. Circuit experimental methodology

Figure 1 shows a PD-type VLC system model with the device that causes stochastic resonance in the receiver. The transmitter consists of a signal generator and one cannonball-type white LED. Similarly, an interference signal generator is also composed of the signal generator and LED. In this study, the same type of LEDs are used as the transmitter and interference signal generators. In this study, the receiver consists of a PIN-PD as a photodetector, a current-voltage converter

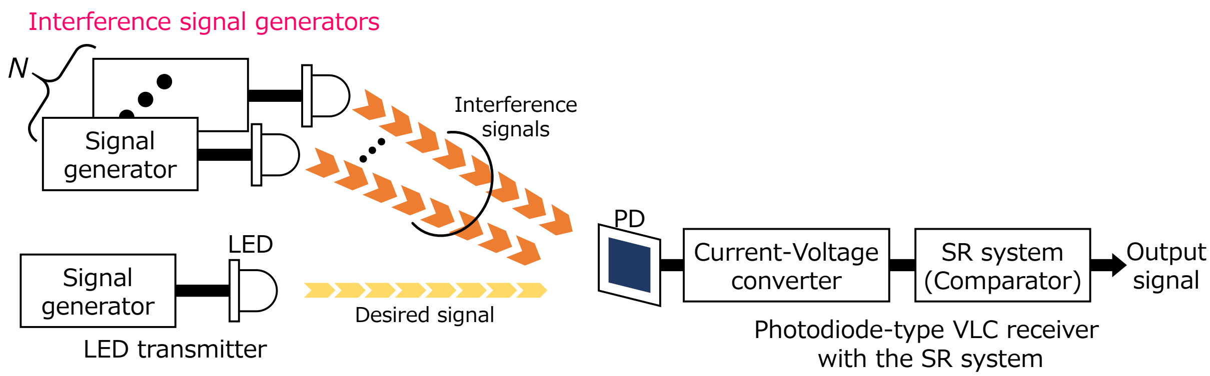


Fig. 1: System model of PD-type VLC with the SR system.

circuit, and a comparator as a device that causes stochastic resonance [18]. The comparator is a circuit that compares the voltages of two signals (input signal and threshold value) and outputs an arbitrary voltage when the input signal is higher than the threshold value.

The circuit operation of the system is explained as follows. To send the desired signal from the transmitter, the LED blinks depending on a square wave that has a pulse length (PL_s) of 100 ms and is generated by the signal generator. In this study, the light intensity of the transmitter is set to a value that does not exceed the threshold of the comparator circuit on the receiver side. At the same time as the transmitter sends the desired signal, the interference signal generators also blink their LEDs according to a random waveform with a pulse length (PL_n) of 10, 1, or 0.1 ms. The PIN-PD on the receiver is placed about 3 cm away from LEDs of the transmitter and interference signal generators, and it receives light from each of them. The current-voltage converter circuit converts the current flowing by the PIN-PD to voltage, which is then inputted to the comparator. Finally, the comparator outputs the signal wave when the input voltage exceeds its threshold value.

Based on the above operation, we performed circuit experiments and observed the stochastic resonance phenomenon by calculating the correlation value C between the desired signal $x(t)$ generated by the transmitter and the output signal $y(t)$ from the comparator as follows.

$$C = \frac{\sum_{t=1}^{T} (x(t) - \bar{x})(y(t) - \bar{y})}{\sqrt{\sum_{t=1}^{T} (x(t) - \bar{x})^2} \sqrt{\sum_{t=1}^{T} (y(t) - \bar{y})^2}}, \tag{1}$$

where T is the signal length, which is equal to the number of times the desired signal is sampled in this study. In addition, $\bar{x}$ and $\bar{y}$ are the mean values of $x(t)$ and $y(t)$, respectively.

Figure 2 shows a schematic circuit diagram of the VLC receiver with the SR system, and Tab. I shows the experimental parameters and equipment. Note that we set the comparator threshold such that it cannot be exceeded by the single LED light of the transmitter, as described earlier. Further,

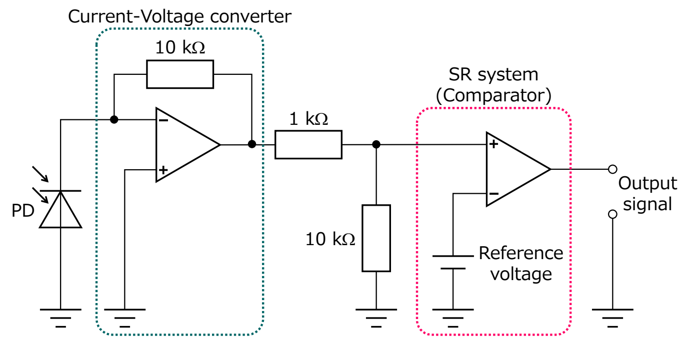


Fig. 2: Schematic circuit diagram of the VLC receiver with the SR system.

we changed the number of interfering LEDs (N) and PL_n, and calculated the correlation C between the transmitted and received signals.

III. Experimental Results

Figure 3 shows the observed signal waveform when the single LED light of the transmitter is received in the PIN-PD without the interfering LEDs. Here, the top, middle, and bottom waveforms in Fig. 3 indicate the desired signal waveform generated by the transmitter, the received signal waveform after passing through the current-voltage converter circuit, and the output waveform after the comparator, respectively. As seen in Fig. 3, although the desired signal is a square wave, it does not appear as the output waveform from the comparator. As mentioned above, this is because the light intensity of the desired signal is purposely attenuated so that it does not exceed the comparator threshold by itself.

Figure 4 shows the observed waveforms when N and PL_n were changed to feed the PIN-PD. In this experiment, N was increased to six, and PL_n was set as 10, 1, or 0.1 ms. As can be seen from these figures, the shape of output waveform from the comparator approaches that of the desired waveform as N increases, namely, the noise intensity increases. Furthermore, it can be easily confirmed that the smaller the PL_n of the random signal generated by interfering LEDs, the more closely do the rising and falling positions of the output waveform

TABLE I: Experimental parameters and equipment.

Experimental environment	Dark room
Distance between LED and PIN-PD	3 cm
Signal waveform	Square wave
Pulse length of desired signal (PL_s [ms])	100
Pulse length of random signal (PL_n [ms])	10, 1, 0.1
Number of times the desired signal is sampled (T)	1000 per one square wave
Number of trial	10
PIN-PD	HAMAMATSU S6775
Operational amplifier	Texas Instruments LM7171BIN/NOPB
LED	Linkman LA504W3CA2C02
Desired signal generator	NF Corporation WF1974
Random signal generator	Arduino UNO R3
Digital oscilloscope	GW Instek GDS-2104A

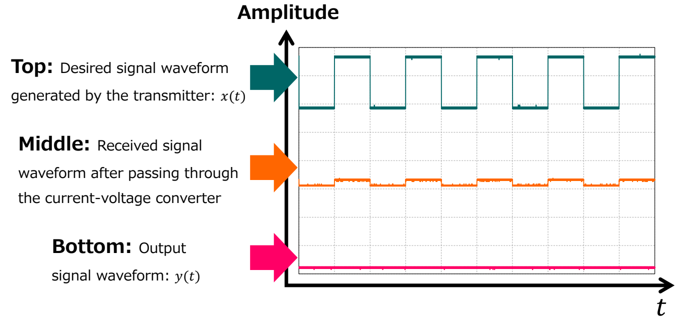


Fig. 3: Observed signal waveform when the single LED light of the transmitter was received in the PIN-PD without the interfering LEDs.

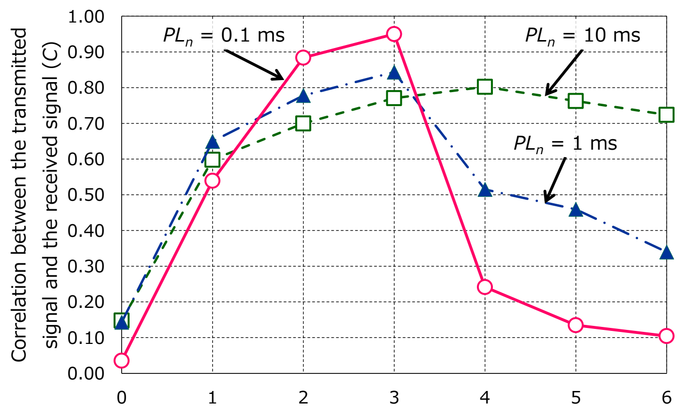


Fig. 5: Correlation C between the transmitted signal and the received signal vs. the number of interfering LEDs (N).

match those of the desired signal. However, when N exceeds a certain value, the output waveform is disturbed immediately and does not resemble the desired waveform.

The similarity between the desired waveform and the output waveform from the comparator was quantitatively evaluated by calculating their correlation C. Figure 5 shows the correlation C between the desired signal and the output signal plotted against N. In this experiment, we changed N and PL_n and observed 10 waveforms corresponding to every parameter value. Then, the correlation values were calculated for each of the 10 observed waveforms and then averaged.

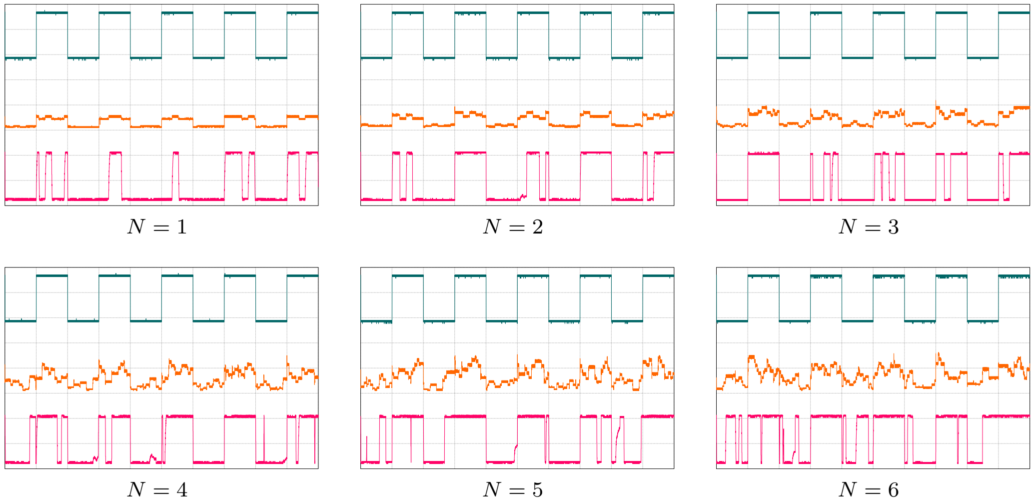
From Fig. 5, we can see that the correlation value increases with N and decreases when it exceeds a certain value. Further, the peak value of the correlation value tends to be appear as PL_n decreases. In this experiment, when $N = 3$ and $PL_n = 0.1$, the correlation value exceeded 0.9. This indicates that the shape of the output waveform from the comparator is almost identical to that of the desired waveform. In other words, the desired signal can be recovered by setting N and PL_n to appropriate values.

Next, let us focus on the timing of the decrease in the correlation C. The decrease in the correlation C depends on PL_n. The smaller the PL_n value, the more rapidly does the correlation value decrease. Correlation C decreases rapidly because the noise intensity increases with N, and the interference signal alone exceeds the comparator threshold regardless of the presence or absence of the desired signal. Furthermore, as PL_n decreases, switching between ON and OFF in the random waveform occurs more frequently, and the sum of the interference signals also exceeds the threshold more often.

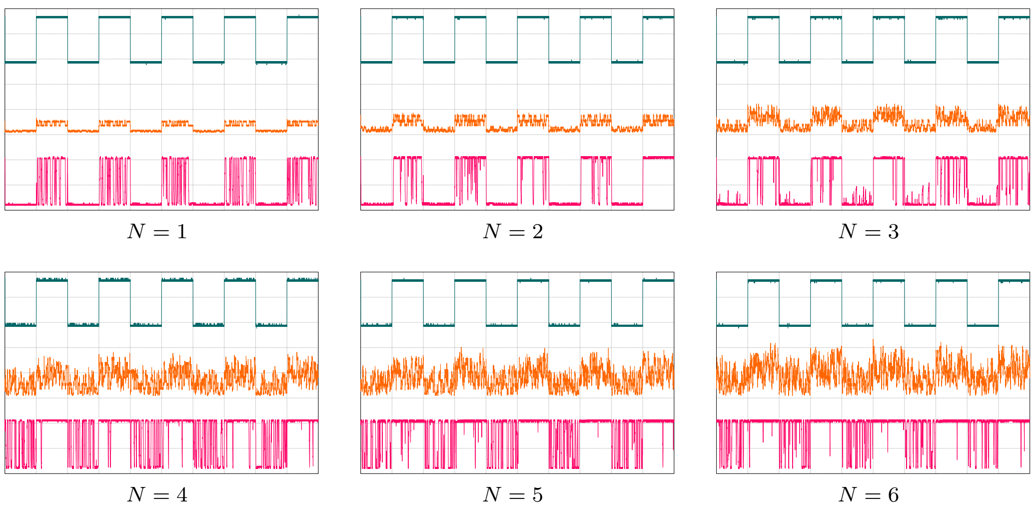
The above experimental results are the typical characteristics of the stochastic resonance phenomenon. Therefore, we found that it is possible to recover the desired signal even if it is weakened to a subthreshold level when the conditions such as N and PL_n are suitable for generating stochastic resonance at the receiver.

IV. Conclusions

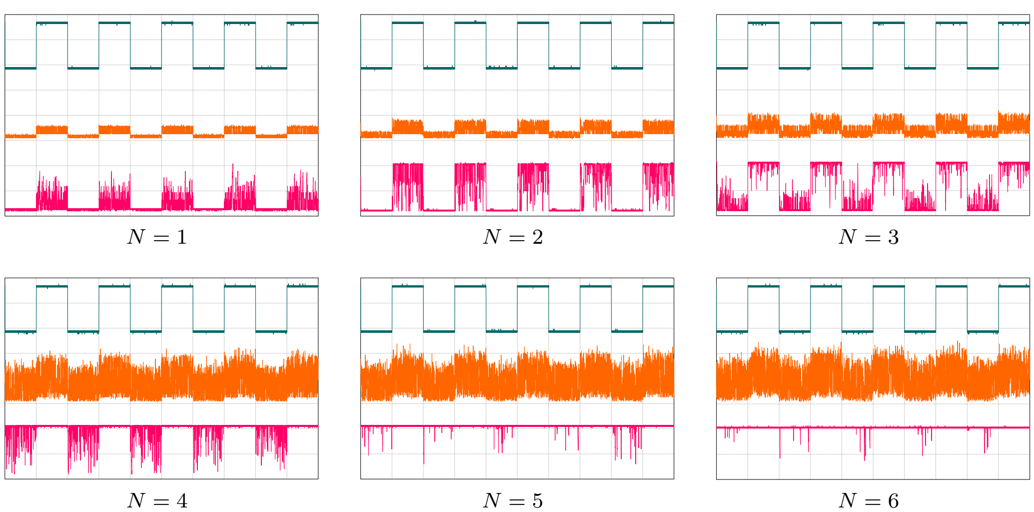
In this study, employed a comparator was used to generate stochastic resonance in the receiver of a PD-type VLC system. An attempt was made to use the stochastic resonance to detect the desired signal, which was weakened to a subthreshold level. The experimental results showed that the stochastic resonance was caused by setting the number of interfering signals and their pulse widths appropriately, and an output waveform with high correlation to the desired signal was obtained at the receiver. As future work, we will conduct communication experiments with an improved version of the experimental circuit proposed herein and evaluate the communication performance, such as bit error rate characteristics.



(a) $PL_n = 10$ ms.



(b) $PL_n = 1$ ms.



(c) $PL_n = 0.1$ ms.

Fig. 4: Observed waveforms when the number of interfering LEDs (N) for feeding the PIN-PD was changed.

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