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A Study on Effective Dimming Control Scheme Using Optical Spreading Codes in Visible Light Communication

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Abstract

In this paper, we proposed a new dimming control scheme by using direct sequence spreading coding (DSSC) scheme in visible light communication (VLC). VLC systems using LED lighting can provide illumination functions and communication services at the same time. In order to provide simultaneous illumination and communication services, dimming control should be considered. Dimming control means that LED lighting should maintain a constant brightness in accordance with user requirements while communication services are offered. In IEEE 802.15.7 VLC standard, on-off keying (OOK) and variable pulse position modulation (VPPM) are defined as pulse modulation schemes for dimming control. In particular, 4B/6B, 8B/10B block coding and Manchester coding schemes have been proposed for stable dimming control in OOK. However, in such a case, stable dimming control is possible although the communication performance is degraded. In order to solve those problems, we propose a VLC system based on OOK modulation with DSSC. The proposed system can simultaneously stabilize dimming control and improve communication performance by obtaining spread diversity gain. The simulation results show that the proposed system provides superior dimming and BER performances compared to conventional dimming modulation schemes.

Keywords: *Visible light communication, Direct sequence spread spectrum, Dimming control, On-off keying, Bit error rate*

1. Introduction

Recently, LED lighting has been used as an effective light source to replace incandescent light bulbs and fluorescent lamps. Visible light communication (VLC) systems using LED lighting can provide illumination functions and communication services simultaneously. Therefore, these systems have attracted attention from both the academia and industry [1-3]. To simultaneously support these functions, avoiding flicker and stable dimming control schemes should be considered in VLC systems [4-5].

Flicker represents the variation in the brightness of the lighting. To avoid flickering problems, the change in brightness should be within the maximum flicker time period (MFTP) [6]. MFTP is defined as the maximum time that the intensity of light can change without being recognized by the human eye. To this end, a frequency above 200 Hz (MFTP <5 ms) is generally considered safe [7]. Therefore, the flicker problem can be solved easily. Dimming control is another important consideration of VLC for power saving and energy efficiency. Dimming control means that LED lighting should maintain a constant brightness in accordance with user requirements while communication services are offered; this can provide energy saving, allow for mood lighting, and increase the

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aesthetic value of a room [8]. Generally, dimming control techniques based on pulse modulation schemes have been researched in VLC systems. In IEEE 802.15.7 standard group, on-off keying (OOK) and variable pulse position modulation (VPPM)) were released for dimming control [9].

OOK is a typical modulation technique most commonly used in VLC systems. This modulation scheme is represented by 'ON' and 'OFF' pulses according to the binary input data. However, these modulation schemes have a disadvantage for dimming control: as the ratio of zero bits is increased in the transmission data, the illumination brightness is also decreased. VPPM is another major modulation scheme for dimming control. VPPM, which combines pulse position modulation (PPM) with PWM, changes both the position and the width of the pulses according to the dimming targets. In terms of dimming control, a major advantage of VPPM is its ability to support a certain brightness level according to the duty cycle ratio [10]. However, when combined with PWM, this modulation scheme has a significant drawback: if the duty cycle ratio is increased in order to improve the brightness of illumination, the bit error rate (BER) performance is also degraded. In particular, VPPM is much more sensitive to channel noise as compared to OOK modulation scheme. Therefore, VPPM cannot ensure quality of communication services (QoS).

In this paper, to solve these problems, we propose a VLC system based on OOK modulation with direct sequence spreading coding (DSSC) scheme. The proposed system can support a stable dimming level regardless of the ratio of 0 and 1 of the binary input data by using the spreading code. At this point, the spreading code must have the same ratio of 0 to 1 code or a higher ratio of 1. Thus, the proposed system can provide a constant dimming level, such as PPM or VPPM. Furthermore, the proposed system is able to obtain the spreading diversity gain, which can lead to improvement of BER performance. To evaluate the efficiency of the proposed system, it is compared with OOK and VPPM in the computer simulation.

This paper is organized as follows. The dimming properties according to several pulse modulation schemes are explained in section 2. The proposed system is described in section 3, and then evaluated in section 4. Finally, this paper is concluded in section 5.

2. Dimming Properties of Conventional Modulation Schemes

2.1. Dimming Properties

In the VLC systems, the modulation schemes that are used convert binary data to the intensity of the light source, while the intensity modulation (IM) is obtained by varying the bias current of the LED devices. The transmitted optical signal should be represented as a positive value, and the average power constraint must be satisfied according to the dimming factor as follows [11]:

$$s(t) \geq 0 \text{ and } \lim_{T\to\infty} \frac{1}{T}\int_0^T s(t)dt \leq \gamma P \tag{1}$$

Where, $s(t)$ is the transmitted optical signal, and T denotes a bit slot duration. Also, P represents the average optical power, and γ is the dimming factor. At this point, the range of the dimming factor should be satisfied for $0 \leq \gamma \leq 1$. If the dimming factor is 0.5, the average brightness level is defined as 50%. Therefore, the brightness can be determined by the dimming factor and the average optical power.

Figure 1 shows the symbol structures of the conventional modulation schemes.

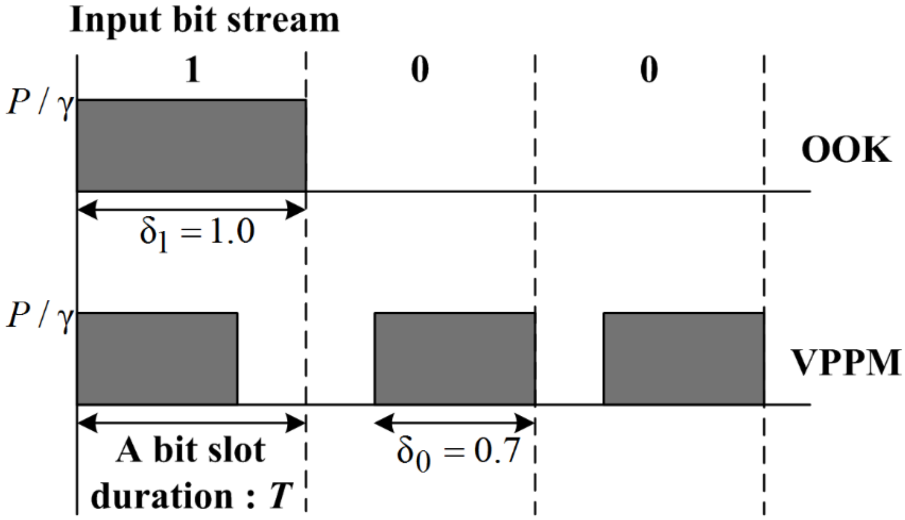

Figure 1. Symbol Structures of OOK and VPPM

In Figure 1, δ_0 and δ_1 are duty cycle ratio (DCR) of 1 and 0 bits, respectively. DCR is defined as τ/T, where τ is the period of time that the pulse is 'ON' [12]. The dimming factor can be defined as follows [13].

$$\gamma = \Pr\left[b=1\right]\delta_1 + \Pr\left[b=0\right]\delta_0 \quad (2)$$

In (2), $\Pr[b=1]$ and $\Pr[b=0]$ are represented as the input ratios of 1 and 0 bits, respectively. Note that the sum of $\Pr[b=1]$ and $\Pr[b=0]$ should always be 1. Therefore, the dimming factors of OOK and VPPM in Figure 1 are 0.5 and 0.7, respectively. In the previously released research results on dimming support, the equal input probability of one and zero bits was assumed, and then the brightness performance was measured. In the case of VPPM, because the data duty cycle ratio of zero and one bits is equal, the brightness performance is not affected by the ratio of entered bits. However, when DCR is increased to improve the brightness level, the BER performance is reduced because the Euclidean distance of 0 and 1 bit is reduced [14]. Moreover, in the VPPM demodulation process, the position of the pulse must be taken into consideration, so it is more affected by noise as compared to OOK.

In the case of OOK, the best BER performance can be achieved because the Euclidean distance of 0 and 1 bits is the largest compared with other modulation schemes [15]. However, the dimming levels of OOK are significantly affected by the input ratio of 0 and 1 bits, and it can lead to unstable dimming support or flicker. To overcome this drawback, Manchester or 8B/10B block coding schemes based on OOK have been proposed to support the stable dimming level. Those coding schemes are referred to as a run length limited (RLL) coding scheme. A detailed description of this coding scheme is explained in the next sub-section section. In the Manchester coding scheme, 0 and 1 bits of the input binary data are expressed by an OOK symbol '01' and '10', respectively. Thus, a constant dimming level of 50% can be supported regardless of the ratio of 0 and 1 input bits. As a result, the Manchester coding scheme based on OOK modulation can be regarded as a 2-pulse position modulation (2-PPM) scheme [16]. The 8B/10B encoder converts 8 input bit strings into 10 input bit strings by adding 2 redundancy bits. At this point, the ratio of 0 to 1 bit of the converted bit string should be equal. As a result, the 8B / 10B coding technique can also support a constant dimming level of 50%. However, the BER performance of these coding schemes is degraded as compared to un-coded OOK modulation. This is because the received signal encoded by Manchester codes should be considered simultaneously about the pulse position to detect their information. Also, in the case of 8B/10B block codes, even if an error occurs in only one code in an encoded code block, it can be decoded into the bit stream of a completely different block in the decoding process. To solve this problem, we propose a VLC system using DSSC technique based on orthogonal spreading codes.

3. Proposed System

The proposed system is able to provide a stable dimming level by applying a DSSC scheme to the VLC systems. To this end, optical orthogonal codes with equal 0 and 1 chip data rates should be selectively used. Figure 2 shows a block diagram of the proposed system.

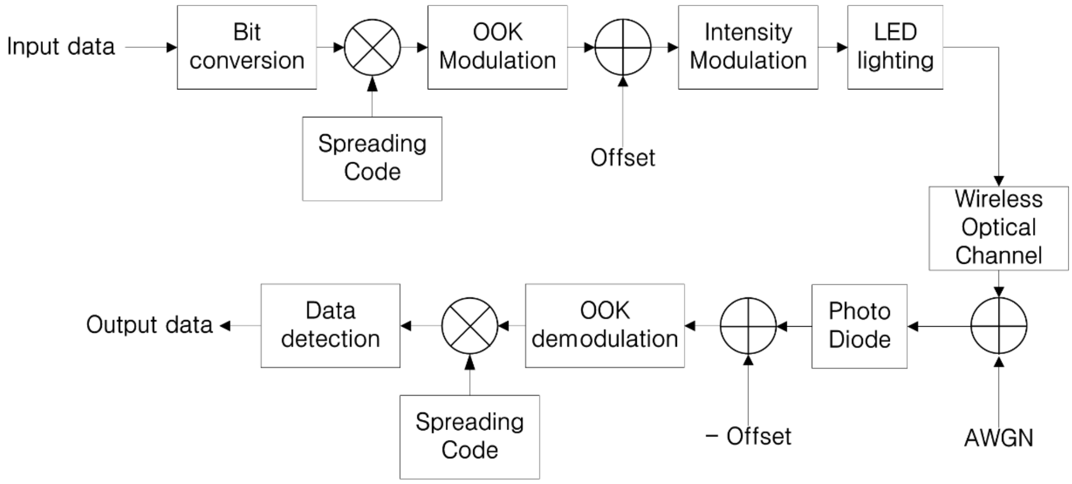

Figure 2. A Block Diagram of the Proposed System

In the transmitter, unipolar input data of 0 and 1 are converted into bipolar data of -1 and 1 to multiply the orthogonal spreading codes. And then, the spreading chip data generate bipolar pulse signals through OOK modulation. Next, in order to convert the bipolar pulse signals into the unipolar pulse signals having no negative value, a constant DC voltage is applied. Finally, those signals are converted into optical signals through intensity modulation and then emitted into receivers.

In a receiver, the incident optical signals are converted into electrical signals by a photo-diode (PD). Then, these signals are recovered as bipolar signals by OOK demodulation after removing the DC offset voltage, which is applied at the transmitter. Finally, the binary data information can be detected by de-spreading process.

4. Simulation Results and Analysis

4.1. Optical Channel Noise Model

VLC is a wireless personal area communication (WPAN) technology which is suitable for indoor environments especially. In outdoor environments, VLC is severely affected by ambient light noise such as sunlight, so the QoS of that cannot be guaranteed. In indoor environments, the wireless transmission paths of an optical signal can be classified into two types: line-of-sight (LOS) and non-line-of-sight (NLOS) paths. Generally, the received signals of LOS path are mainly affected by adaptive white Gaussian noise (AWGN) and received optical power, where the main factors of received optical power are the incidence angle and transmission distance. However, power loss can be compensated according to the incidence angle. This is because band-pass optical filters and a hemispherical lens have been used to attenuate ambient light and achieve a wide field of view (FOV) [17]. Based on those characteristics, the path loss of optical signals according to the incident angle can be mitigated. Hence, the main reason for path loss in VLC systems can be assumed as the transmission distance.

On the other hand, the received signal of NLOS path should take into account the effects of waves reflected by obstacles or walls, and it leads to inter-symbol interference (ISI) by time delay between received signal and reflected signal. Therefore, the BER performance is degraded than the received signal of LOS path. However, the characteristics of the LOS and NLOS channels are not considered major factors in the proposed system. For this reason, this paper considers only the LOS channel.

The desired signals contain a time-varying shot-noise process which has an average rate of 10^4 to 10^5 [photons/bit]. However, the intense shot noise has a rate of order of 10^7 to 10^8 [photons/bit]. Therefore, we can neglect the shot noise as a Gaussian process [18]. Also, multipath fading can be neglected in the wireless optical channel. Generally, information carrier is light-wave whose frequency is about 10^{14} [Hz]. So, the Doppler frequency of fading is higher than the data rate. Also, detector dimensions are of the order of thousands of wavelengths, leading to efficient spatial diversity that prevents multipath fading. Due to above reasons, multipath fading can be neglected [19].

4.2. Simulation Results

In order to evaluate the dimming and BER performance of the proposed system, computer simulations are performed, and Table 1 shows the summarized simulation parameters.

Table 1. Table Label

Parameters	Values
Data rate	100, 200 [Mbps]
The number of users	3
Pulse modulation	OOK, VPPM
Optical modulation	IM-DD
Spreading code length	2, 4, 8
Optical channel model	LOS (only LOS)
O/E conv. efficiency	0.53 [A/W]
Background noise power	1 [m/W]

In our simulations, the data rate is set to 100 and 200 [Mbps]. Also, optical to electrical (O/E) converter efficiency and background noise power are assumed to be 0.53A/W and 1mW, respectively. The lengths of the orthogonal spreading codes are set to 2 and 4 (*i.e.* SF=2, 4).

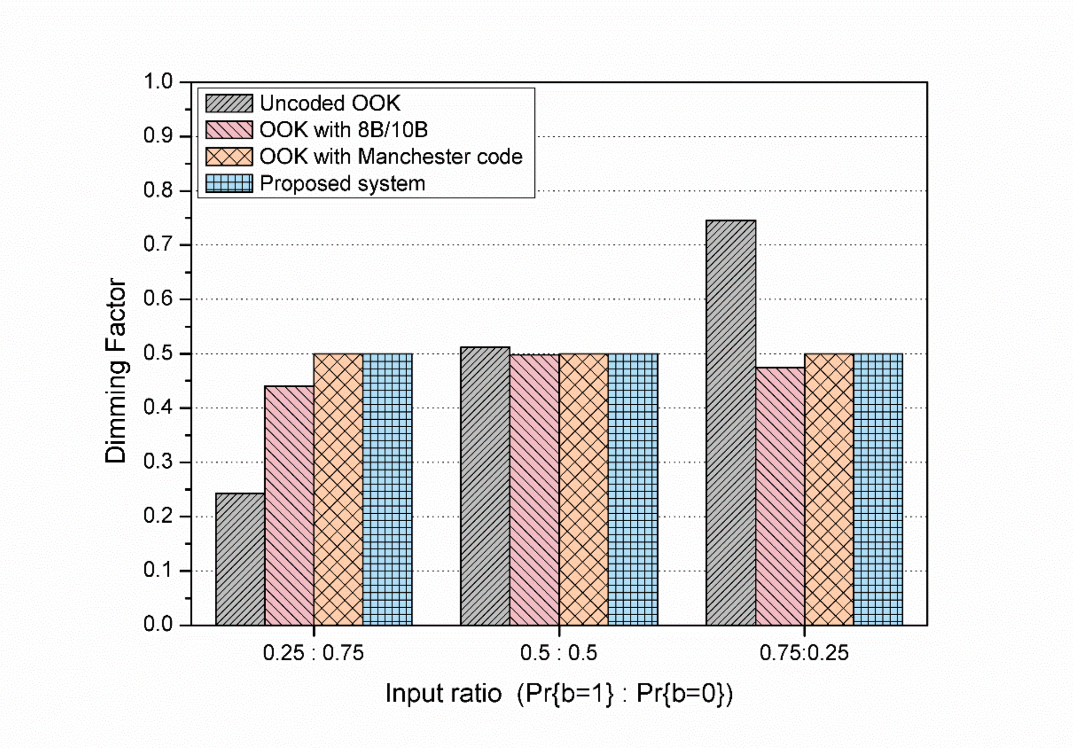

Figure 3. Comparison of Dimming Levels According To Several Dimming Control Schemes

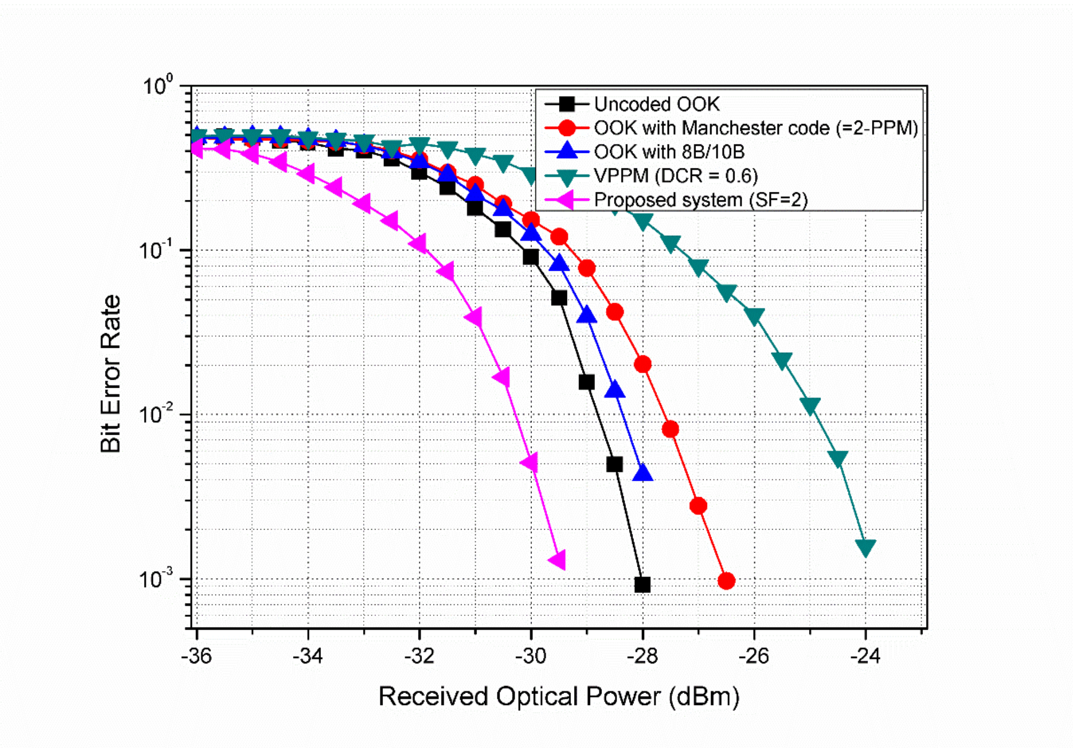

Figure 4. Comparison of the BER Performance According To Several Dimming Control Schemes

Figure 3 shows the dimming factor results according to several dimming schemes based on OOK modulation. In this Figure, the x-axis means the input ratio of 0 and 1 bits. In the case of the un-coded OOK modulation, it can be seen that the dimming levels greatly depend on the input data ratio of 0 and 1 bits. In the case of both the proposed system and OOK modulation with Manchester codes, a constant dimming level of 0.5 can be achieved, regardless of ratio of the input data. Meanwhile, in the case of the 8B/10B block code, it can be confirmed that a constant dimming level is not achieved, but that is achieved around 0.5. This is because some block code sets in the transform code set cannot provide an equal ratio of zeros and ones.

Figure 4 shows the BER performance for each dimming technique. In the case of OOK modulation with Manchester codes, it is equal to VPPM at the dimming factor 0.5, because it can be considered as 2-PPM. From Figure 4, when the Input data is encoded in Manchester code, the BER performance is the worst of the dimming schemes based on OOK modulation. In addition, as the dimming factor increases, the BER performance deteriorates drastically. This is because the decision interference is increased due to overlapping the decision boundary. In the case of the 8B/10B block codes, the BER performance is also degraded as compared to the un-encoded OOK modulation. However, our proposed system can improve the BER performance by obtaining the spreading gain. This is because orthogonal spreading codes of the proposed system have the characteristics of ideal auto-correlation and cross-correlation. Therefore, the proposed system can mitigate BER performance degradation due to channel interference better than compared with conventional systems.

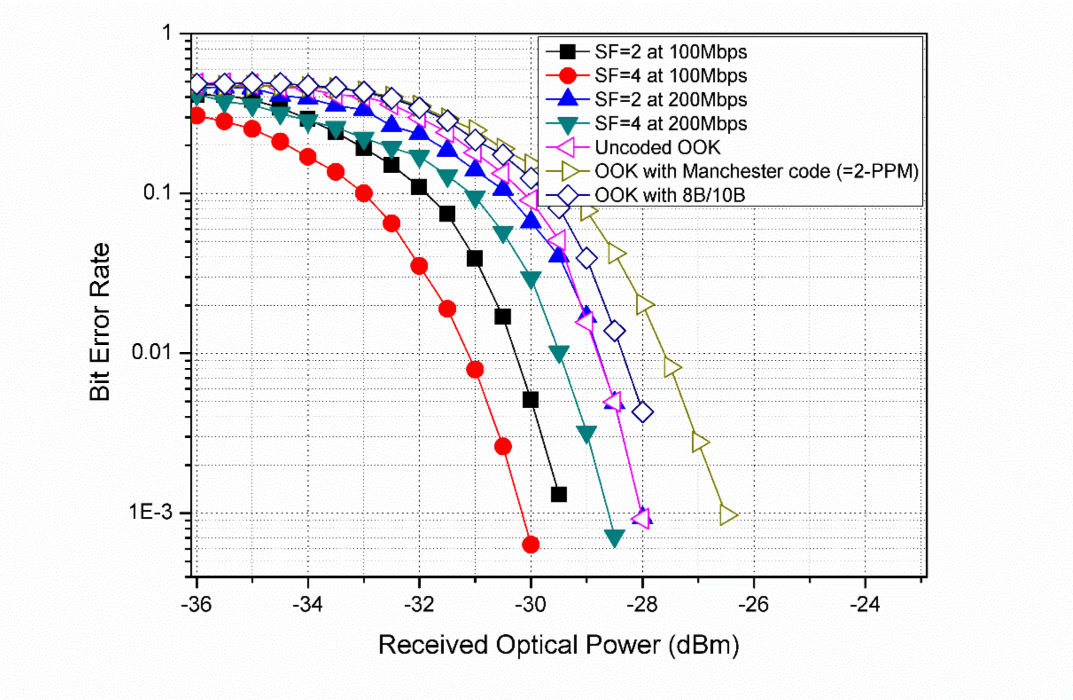

Figure 5. BER Performance of the Proposes System at SF=2, 4 and data rate=100, 200Mbps

Figure 5 shows the BER performance of the proposed system according to the SF length and the data rate. The results demonstrate that the BER performance is improved when the spreading code length was increased in the proposed system. Furthermore, even when the transmission rate of the proposed system is 200 Mbps, the enhanced BER performance can be achieved better than conventional dimming schemes.

5. Conclusions

In this paper, DSSC scheme is applied to VLC systems for stable dimming control. The proposed system can support a constant dimming level similar to 2-PPM (*i.e.* OOK modulation with Manchester codes), regardless of the input ratio of 0 to 1 bits. Also, the proposed system can improve the BER performance significantly in comparison with conventional dimming schemes by using the properties of orthogonal spreading codes. As a result, the proposed system can support the stable dimming level and improve the BER performance simultaneously, and those features are expected to be a suitable technology for VLC.

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