A Study on Limitations in VLC Systems

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Abstract— Mitigation of nonlinearity is very important factor as it influences the performance of a visible light communication (VLC) system. In this paper several nonlinearities and limitations of VLC systems are analyzed as a review study and detailing about some previous papers to develop a new logic as well as researching for VLC systems and future scopes to make a VLC system reliable. Nonlinearity is discussed and mainly focused in this paper as a main limitation of VLC. This paper discusses about a mitigation technique which is already proposed with micro light emitting diodes (LED) in cooperation with multiple access schemes here mainly CDMA is considered. Nonlinearity limits the performance in terms of bit error rate as well as error vector magnitude. Nonlinearity mitigation methods are proposed earlier but that system designs are not suitable for indoor and industrial applications, because such design required additional circuits, which make the system high cost and complex. This paper can be considered as a literature survey or a case study to analyze VLC and a search for new scopes in VLC.

Key words: VLC, LED, Nonlinearity, CDMA

I. INTRODUCTION

In real world applications, communication can be classified into different categories. One of the recent and widely used wireless communication techniques[2] is visible light communication. As a subset of optical communication, VLC is a data communication variant which uses visible light between 400 and 800 THz (780- 375 nm). It is a subset of optical wireless communications technologies. The technology uses fluorescent lamps to transmit signals at 10 kbit/s, or LEDs for up to 500 Mbit/s. The specially designed electronic devices generally containing a photodiode receive signals from light sources, although in some cases a cell phone camera or a digital camera will be sufficient. The image sensor used in these devices is in fact an array of photodiodes and in some applications its use may be preferred over a single photodiode. Such a sensor may provide multichannel communication or a spatial awareness of multiple light sources. VLC can be used as a communications medium for ubiquitous computing, because light producing devices such as indoor[2] or outdoor lamps, TVs, traffic signs, commercial display and car headlights or taillights are used everywhere.

Using visible light is also less dangerous for high power applications because humans can perceive it and act to protect their eyes from damage. In a VLC system, the modulation bandwidth of light emitting diode is limited with current technology. The visible light spectrum has a larger bandwidth than conventional radio frequency wireless spectrum. VLC has enlightened a new direction of research as it has the potential to meet increasing demand of future wireless data transmission. On the other hand, with current LED technology, the modulation bandwidth of the LED, which acts as the transmitter in the VLC system, is limited to a few tens of MHz[5].

VLC is considered a strong contender for the next generation of indoor communications and networking Integrating VLC networks with illumination systems imposes limitations on the modulations and networking techniques that can be used. White light emitting diodes are the most common optical sources that are used in VLC systems, and modulation schemes that can be used with these devices are limited. Because of the structure of these LEDs and their inherent nonlinearity[5], implementing modulation and networking approaches that require spectral encoding is expensive and complicated. Therefore, time spreading modulations, specially pulsed techniques, are the preferred modulation technique in LED based VLC systems.

Visible light communication has attracted much attention in recent years for the practically unlimited wireless spectrum. The VLC system can achieve a peak data rate of 4.2 Gbits/s with a red-green-blue light emitting diode. The nonlinearity of LED, on the other hand, is not negligible, which limits the system performance in terms of bit error rate and error vector magnitude. An optical code division multiple access schemes for VLC systems was proposed, which exhibited the property of canceling multi user interference. Techniques based on multilevel signaling and optical orthogonal codes were explored and provided multiple access in an indoor multiuser network. In a color shift keying CDMA VLC system which could support multiple users simultaneously is proposed and performed. A 3 dB transmission gain was obtained compared with the conventional point-to-point OOK modulation[6]. Many physical devices used in VLC systems exhibit nonlinear effects, which can significantly degrade the overall system performance. For example, the LED is the major source of nonlinearity.

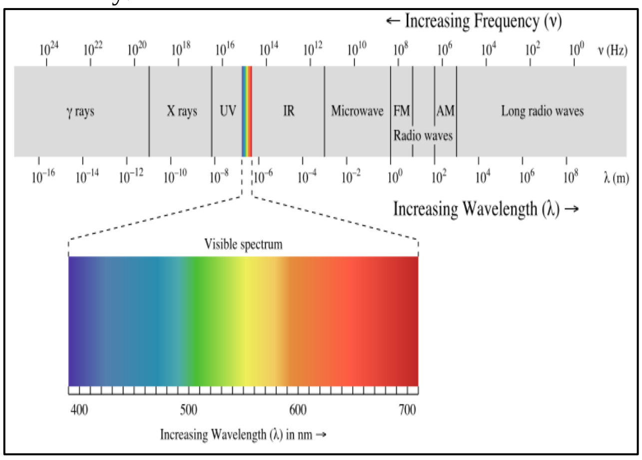


Fig. 1: EM spectrum specifying visible light.

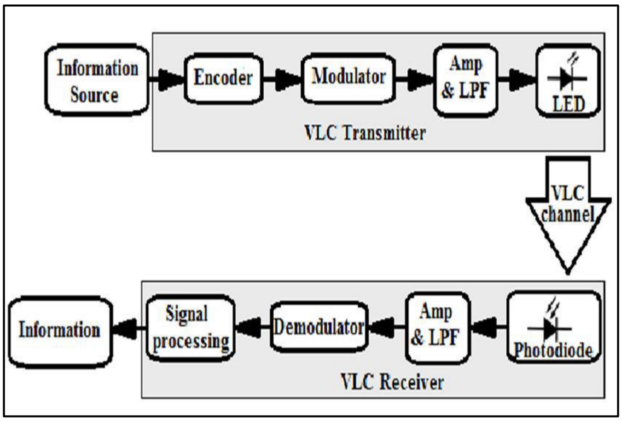
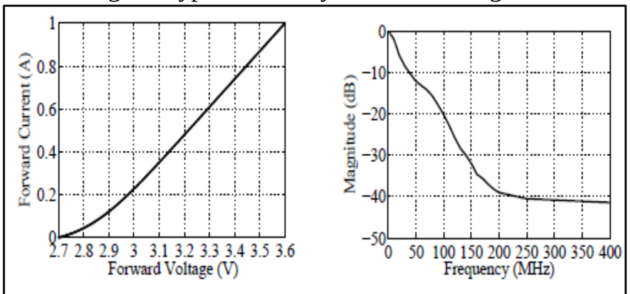


Fig. 2: Typical VLC system block diagram



(a) I-V transfer function. (b) Frequency response.

Fig. 3: Nonlinear characteristics of LED

Typical block diagram of a VLC system is shown in figure 2. VLC is a subset of optical wireless communication therefore LED is the transmitter which converts the electrical signal to light and photodiode is the receiver which converts optical signal to electrical signal. Visible light communication channel is free space channel in line of sight with LED and device to communicate. The nonlinear characteristics of LED are shown in figure 3. This paper deals with the study of limitations of a VLC system due to nonlinearities caused by different components in a designed system. This paper mainly contributes a detailed survey or a summary of non linearity and the methods to avoid this problem to design a reliable VLC system.

II. REVIEW STUDY

A wide variety communication system is available using VLC, but always search for a reliable and fast system when compare with all the existing systems. There are some familiar communications systems which can be consider as the existing systems which deals with nonlinearities of visible light communication. Interconnecting devices in an indoor environment using the illumination system and white light emitting diodes requires adaptive networking techniques that can provide network access for multiple users. Two techniques based on multilevel signaling and optical orthogonal codes are explored in this paper in order to provide simultaneous multiple access in an indoor multiuser network. Balanced incomplete block designs are used to construct multilevel symbols for M-ary signaling[6]. The first approach has a larger Hamming distance between the symbols of each user, the latter can provide higher bit rates for users in VLC systems with bandwidth limited LEDs.

Optical code division multiple access is a networking technique that provides multiple access by assigning binary signature patterns to users. Among various OCDMA forms that have been proposed, time-spreading OCDMA is of most interest for indoor VLC system, since it can simply be implemented by turning the LEDs on and off. In this type of OCDMA[5], binary sequences with special cross correlation constraints, so called optical orthogonal codes, are used to encode the data of users in the time domain. Codewords of an OOC are binary sequences that meet a given correlation constraint. The application of OOCs to VLC networks requires codes with a wide range of parameters for different dimming levels, which may not be practical for a network with a fixed number of users. To apply expurgated pulse position modulation and multilevel EPPM[6] and to indoor VLC systems in which the dimming can be done by simply changing the generating balanced incomplete block design (BIBD) code. A basic OW system consists of a light source, free space as the propagation medium, and a light detector. Information, in the form of digital or analog signals, is input to electronic circuitry that modulates the light source. The source output passes through an optical system into the free space. The received signal comes through an optical system, passes along the detector, and the resulting photocurrent is amplified before the signal processing electronics. For most indoor applications, LEDs are the favored light sources due to the relaxed safety regulations, low cost, and high reliability compared to laser diodes. PIN photodiodes are commonly used due to their lower cost, tolerance to wide temperature fluctuations, and operation with an inexpensive low bias voltage compared to avalanche photodiodes. Simple and low cost optical carrier modulation and demodulation are usually achieved through intensity modulation with direct detection. The desired waveform is modulated onto the instantaneous power of the optical carrier, and the detector generates a current proportional to the received instantaneous power.

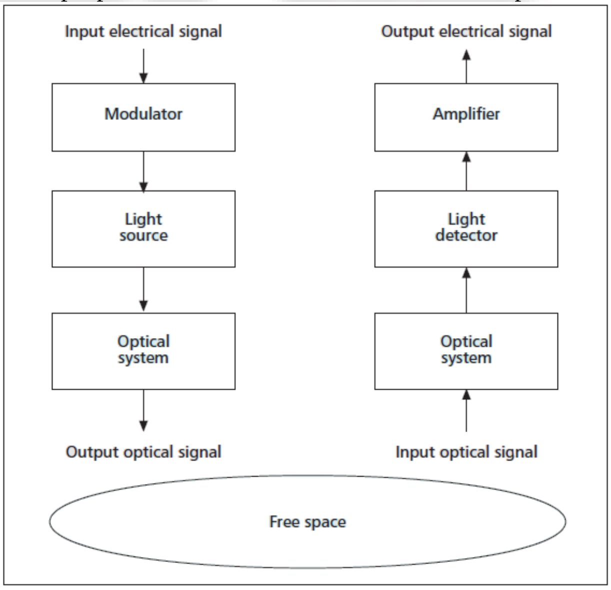


Fig. 4: Block diagram of a typical indoor OW system

A block diagram of a typical indoor OW system is figure in figure.4. A basic OW system consists of a light source, free space as the propagation medium, and a light detector. Information, in the form of digital or analog signals, is input to electronic circuitry that modulates the light source. The source output passes through an optical system into the free space[2]. The received signal comes through an optical system, passes along the detector, and the resulting photocurrent is amplified before the signal processing electronics. In optical systems, the LED is a major source of nonlinearity. This nonlinear behavior is particularly important when analog OFDM modulating. The LED nonlinear behavior degrades the bipolar time domain DCO-OFDM signal through amplitude distortion, clipping of the lower peaks, and clipping of the upper peaks. The lower peaks are clipped at the turn on voltage of the LED, and the upper peaks are clipped at the saturation voltage, which corresponds to the maximum permissible AC or pulsed saturation current of the LED recommended by the manufacturer. The clipping of the upper peaks ensures that the LED chip does not overheat, in order to avoid degradation in output light or, in the worst case, total failure. In order to control the LED nonlinearity induced distortion, searching for an optimum DC operating point and optimal OFDM signal power to modulate the LED intensity is required, i.e. to operate the LED in a quasi linear segment of its characteristic around the chosen DC operating point. Selecting an LED with high AC or pulsed current level, i.e., large dynamic ranges, enhances the performance. Moreover, error performance is improved by considering an LED with low voltage-current slope characteristics. Additionally, a predistorter that uses the LED inverse characteristics as nonlinear distortion compensator, indeed, peak to average power ration reduction techniques can also be considered to reduce power backoff levels.

To construct digital predistorters for LEDs, first identify the LED nonlinear transfer function and then find the inverse of it so that the cascaded function is in accordance with the desired mapping that we design. This approach can be called static predistortion[8]. Figure.5.(a) shows a general structure of this approach. To simplify the description, omit modulation, demodulation, DAC, and ADC from the figure. In practice, for memory less nonlinearities, the static predistorter can easily be implemented with lookup tables that map the original input constellation points to the desired locations after we know the LED nonlinearity. For nonlinearities with memory, memory less predistortion[8] can only achieve limited linearization performance, so predistorters also need to have memory structures. Similar to nonlinearities modeling, the models for predistorters include the Volterra series and its special cases like the Hammerstein model and the memory polynomial model. In most cases, obtaining the inverse of a nonlinear system is not easy, especially with memory or time varying characteristics. Another type of approach is to model and estimate the predistorter directly from sampled data by reversing the data flow and assuming the output of the LED as the input of the predistorter and the input of the LED as the output of the predistorter. The advantage of this approach is that it eliminates the need for model assumption and parameter estimation of the LEDs. Figure 5 (b) shows the general structure of this approach, which is also called adaptive predistortion[8].

The principle of the adaptive predistortion is shown as follows. First choose the predistorter with a specific model such as the memory polynomial model. Then we compare the output of the LED with the desired value so that we can adjust the parameters of the predistorter[8] to minimize the difference. The difficulty is how to obtain the feedback of the LED output since we care about the light intensity. In RF predistortion systems[8], it is straightforward to tap off an electrical signal after the power amplifier. However, in VLC, the LED is the source of distortion and the output of the LED is light, which is harder to measure. One possible way is to put a PD beside the LED transmitter to feedback for predistorter training. However, the PD is a nonlinear device as well, and the implementation cost is not favorable.

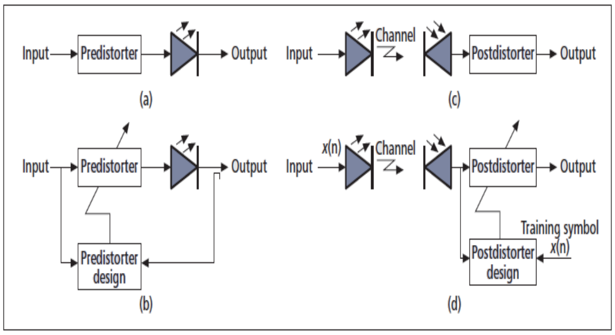


Fig. 5: (a) static predistortion; (b) adaptive predistortion; (c) static postdistortion; (d) adaptive postdistortion.

Postdistortion is a receiver side technique to mitigate nonlinear distortion. Figures 5(c) and 5(d) show the general structures of the static postdistortion[4] and the adaptive postdistortion techniques. Similar to static predistortion, static postdistortion only takes the offline data of the nonlinearity and cannot support the LED nonlinearity dynamics. For dynamic postdistortion, no additional feedback physical circuits are needed as in adaptive predistortion[4]. Compensation for LED nonlinearity is achieved by means of Volterra receivers. An adaptive postdistortion technique with the memory polynomial model and improved system performance was proposed. Postdistortion[4] can also be combined with frequency domain equalization to compensate for the memory effect caused by non flat frequency response of LED. In most cases, only the line of sight link is considered for channel modeling since it is usually much stronger than the diffuse link. In addition, the signal bandwidth is narrow due to the limited LED response. Thus, the frequency response of an IM/DD channel is relatively flat. However, consider that multipath effects or the modulation bandwidth is relatively broad, the channel response is no longer flat. In this case, it may be necessary to combine pre-equalization or post-equalization with predistortion[7] or postdistortion[4] to compensate for the channel response. The nonlinear effects in the VLC system are different from the conventional wireless communications system. The channel separation in the VLC system is significantly larger than the signal bandwidth; thus, the adjacent channel interference is not an issue. Predistortion technique may not be a cost efficient approach since it needs additional feedback physical circuits at the transmitter. A postdistortion technique to estimate and compensate for the LED's nonlinearity at the receiver was analyzed. The postdistortion technique[4] only needs some additional computational resources. This approach significantly improves the EVM and BER performance of the VLC system.

On one hand, unlike the wireless communications system, the channel separation in the VLC system is significantly larger than the signal bandwidth, thus the ACI performance is not an issue. On the other hand, the adaptive post-distortion only needs some computational resources without any additional physical circuits at the receiver. The adaptive post-distortion technique is more cost efficient than the adaptive predistortion technique and is easier for implementation compared to the Volterra equalizer[3]. In the transmit path, information bits are modulated to time domain signals by the modulation block, which supports OOK, VPPM, pulse amplitude modulation (PAM), OFDM, etc. Then, the modulated signal is converted to analog domain signal by a digital to analog converter[3]. A direct current bias is necessary to ensure that the LED's input signal works in the operational region. In the receive path, a photodiode is utilized to detect the light intensity[3]. The analog signal is sampled by the analog to digital converter and processed by the demodulation block.

CDMA transmission scheme that supports multiple access as well as variable data rate for different users is proposed. The proposed scheme[1] is based on multiple LEDs structure that each LED element in the transmitter only transmits binary bit 0 or 1, which avoids nonlinear distortion. The overall transmission is thus linear with respect to the overlayed signal. The micro LED array device that enables VLC system with wider modulation bandwidth is ideal for the proposed CDMA architecture. It is demonstrated that data transmission at rates up to 1 Gb/s was achieved from a single pixel on micro LED array. With micro LED array structure, the optical 3 dB modulation bandwidth was in excess of 400 MHz. A VLC system with micro LED array that avoids the nonlinearity in the device is proposed. In this paper, a CDMA architecture based on micro LED array is proposed[1], which enjoys the benefits of wide modulation bandwidth. The proposed scheme also provides multiple access as well as variable data rate with no nonlinear impairments. This system reduces to a point to point communication system when there is only one user. In order to accommodate multiple users at the same time without interfering each other, a set of orthogonal spreading codes is applied to the information bits from different users. At the transmitter, the information symbols are spread to time domain chips. At the receiver, the despreading operation converts the time-domain chips into transformed domain symbols. The nonlinear distortion applied in the time domain could be treated as additive white noise in the frequency domain. Such property holds for general orthogonal linear transforms.

Conventional CDMA scheme applied to the VLC system does not take the nonlinearity of the LED into account. So a multiple LEDs based CDMA architecture[1] is considered. Assuming that the LEDs used in this proposed system are the same. Different from transmitting the multiplexed data within one single LED, the modified multiple LEDs structure transmit data of different users with separated LED elements. In each LED, the input data modulated with BPSK[1] exhibit constant envelop. Even the LED is driven into the saturation region, the binary output can still be viewed as linearly amplified input and, thus, is immune to the LED nonlinearity. In most cases, line of sight channel exists in VLC communications and the multiple LEDs in the transmitter are placed close to each other. It is reasonable to ignore the MIMO effects at the receiver and the received signal can be viewed as a superposition of signals from each individual LED transmitter. At the receiver side, each user can recover its own information bits with the corresponding spreading codewords. With the multiple LEDs structure, reduces to the linear case. The performance gain of the CDMA scheme is preserved even with nonlinear LED. The proposed multiple access[1] architecture, however, suffers from several practical limitations. Firstly, the synchronization of signals in different LEDs needs to be performed since the orthogonality of different users relies on the time synchronization. Second, the consistency of different LEDs may affect the system performance as well. The DC bias of each LED needs to be added independently and may introduce mismatch[1]. CDMA VLC architecture with digitally controlled micro LED array is proposed. Comparing to conventional multiple LEDs, the micro LED array enjoys higher integration, wider modulation bandwidth and better consistency among array elements. The input control and biasing control of each array elements are easy to implement. Meanwhile, dithering technique can be applied to overcome the mismatch of different elements and extend the life span of the elements in micro LED array. The CDMA VLC architecture with micro LED array[7] is appropriate for multiple access.

VLC system has many applications in day to day life, it focus to be applicable in short distance communication such as, indoor environments [6], Internet of things and machine to machine communication, museums of illuminate the collection and also for remote monitoring to transmit information about them, Li-Fi is the most useful application, in closed room applications maximum internet access possible without any fading, consumer devices, traffic communications especially in signal lights.

III. CONCLUSION

Nonlinearity is very important factor in VLC system. It affects the performance of the system. This paper deals with nonlinearities and limitations of VLC systems were analyzed as a review study. To develop a new logic for VLC system, research and review should be a main parameter, so this paper can be concluded wisely as it met both aspects. This paper discusses about various reasons for nonlinearity and the mitigation techniques such as by using micro light emitting diodes in cooperation with multiple access schemes, distorters, delta modulators. Nonlinearity limits the performance in terms of bit error rate as well as error vector magnitude. Nonlinearity mitigation methods are proposed earlier but that system designs are not suitable for indoor and industrial applications, because such design required additional circuits, which make the system high cost and complex. This paper is considered as a literature survey or a case study to analyze VLC and a search for new scopes in VLC. Thus some future scopes are observed to implement in upcoming researches.

IV. FUTURE SCOPES

Future advancements in this system can be implemented in terms of its limitations. To achieve a high data rate transmission, OFDM can be implemented, optimize the transmission power for high illumination. Equalizer can be used to remove MUI and ISI. Signal processing techniques such as filtering can be implemented to remove noises or shadows. SNDR can be optimized to improve the signal strength. Provide line of sight to overcome dimming effects. Further scopes in advancements are researching and are implementing in nearby years.

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