

A Flicker Mitigation Modulation Scheme for Visible Light Communications

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Abstract—LED (light-emitting diodes) lighting is steadily finding its way into the market of artificial illumination. An additional characteristic of LED lighting is the ability to accommodate switching times that are high enough to transmit data via the visible light it emit. This paper proposes a scheme for providing a data transmission with less flicker in VLC (visible light communication). The scheme utilizes a modulation using dual slope pulses. Due to its moderately increasing and decreasing pulse characteristic. This scheme can also be effectively used in an extremely low light condition. A recovery process in the receiver is proposed.

Keywords—visible light communications, wireless personal area network, pulse dual slope modulation, light dimming, flicker mitigation

I. INTRODUCTION

As the demand for wireless data transmission constantly increases, the radio frequency spectrum is becoming increasingly congested. The attention has been drawn towards alternative technologies. The abundance of unregulated bandwidth at the optical frequencies makes optical wireless technologies attractive candidates for the future local area network [1]. Optical wireless communications using infrared light-emitting diodes (LEDs) was first proposed by Gfeller and Bapst [2], while optical wireless communications with LEDs emitting in the visible spectral range has recently received increasing attention and is commonly referred as visible light communication (VLC) [3] [4]. In some use cases, LEDs in VLC systems serve a dual role in providing both illumination and wireless connectivity [4]. The IEEE 802.15.7 task group has finished a global VLC standard in September 2011.

VLC transmits data by modulating the LED intensity faster than the persistence of the human eye. The optical output power of the source is simply varied according to the modulated signal. OOK (on-off keying), PCM (pulse code modulation) and SC-BPSK (sub-carrier binary phase shift keying) are some of modulation schemes proposed in conjunction with VLC. [5] During the data transfer, the average optical power may change giving rise to a flicker. A flicker means the periodic or nonperiodic output power (brightness) fluctuation which human eyes can perceive. It can fatigue the eyes quickly and deteriorate the eye sight if they are exposed to a noticeable flickering lighting for a long period of time. The flicker in VLC is classified into two categories, an intra-frame flicker and an inter-frame flicker. The intra-frame flicker appears from the

brightness discrepancies between the bit patterns of “1” and “0” inside a data frame. The inter-frame flicker is caused by the average brightness discrepancy between the packet frame transmission period and the idle period. It is easily speculated that the LED light flickers more in a low data rate than in a high data rate.

Dimming is an essential functionality of modern lighting systems. In the case of LEDs, pulse-width modulation (PWM) seems to provide the most effective means of accurately controlling LED illumination without incurring color rendering of the emitted light [6] [7]. In PWM, the brightness is controlled by adjusting the duty cycle of the pulse train. Either when the data rate is low or when the idle period is long compared to the data transmission period, the flicker becomes more noticeable. This paper proposes a modulation scheme which reduces significantly the flicker problem. The modulation scheme utilizes the pulse dual slope modulation (PDSM) scheme proposed by Anand and Mishra [8].

The paper is composed as follows: this section constitutes the introduction. Section II briefs the operation of the light dimming and flicker-mitigation proposed in IEEE 802.15.7. Section III describes the proposed PDSM scheme and a recovery process at the receiver. Section IV concludes the paper.

II. IEEE 802.15.7 LIGHT DIMMING AND FLICKER-MITIGATION METHODS

The IEEE 802.15.7 task group has recently finished the VLC standard in September 2011. [9] The IEEE 802.15.7 standard supports several dimming and flicker-mitigation methods. In this section, those standardized methods are briefed to see how various dimming and flicker-mitigation schemes operate.

A. Idle Pattern and Compensation Time Dimming

The IEEE 802.15.7 standard allows an idle pattern to be inserted between the data frames for light dimming. The duty cycle of the idle pattern can be varied to provide brightness variation. The idle pattern can either be in-band or out-of-band. An in-band idle pattern does not require any change in the clock and can be seen by the receiver. An out-of-band idle pattern is typically sent at a much lower optical clock and is not seen by the receiver (i.e., it does not lie in the receiver’s modulation-domain frequency band.) The standard also allows

a compensation time (“on” or “off” time of a light source) to be inserted into either the idle pattern or into the data frame to reduce or increase the average brightness of a light source.

B. Visibility Pattern Dimming

Visibility patterns are in-band idle patterns that are used in the payload of a CVD (color visibility dimming) frame. The CVD frame is a frame used for color, visibility and dimming support. The CVD frame provides information such as communication status and channel quality to the user via various colors. The CVD frame may also be sent during idle or receive modes of operation for continuous visibility and dimming support. During the CVD frame transmission, the device is still emitting light while not communicating, and it is thus able to fulfil its lighting function. The payload of the frame consists of visibility patterns of appropriate intensity and color. The visibility patterns are used for supporting features such as flicker mitigation, continuous visibility, device discovery, and color stabilization. The visibility patterns are not encoded in the PHY layer and do not have a frame check sequence (FCS) associated with them. In order to generate high resolution visibility patterns from 0% to 100% in steps of 0.1%, there are certain constraints that need to be used in the design criteria for visibility patterns. a) The number of transitions between ones and zeros can be maximized to provide high-frequency switching in order to avoid flicker and to help the clock and data recovery (CDR) circuit at the receiver for synchronization purposes, if used. b) Visibility pattern generation can be made in a simple manner. Designing a thousand patterns to support low resolutions (as low as 0.1% resolution) is not practical and makes visibility pattern generation and use very complex. c) Since visibility patterns are transmitted without changing the clock frequency (in-band), the patterns avoiding conflicts with existing RLL (run-length limited) code words are recommended.

C. Color-Shift Keying (CSK) Dimming

CSK supports VLC using multi-color light sources and photo detectors. CSK has the following advantages:

- 1) Information is provided by the color coordinates: CSK channels are defined by mixed colors that are allocated in the color coordinate plane; therefore, the connectivity is facilitated by the color coding.
- 2) Total average power is constant: The total average power of all CSK light sources is constant; therefore, the envelope of the sum of all light signals is constant.
- 3) Variable bit rate: CSK enables variable bit rate due to higher order modulation support; that is, the raw bit rate equals the optical clock rate times the bits per CSK symbol. CSK dimming employs amplitude dimming and controls the brightness by changing the current driving the light source. However, a color shift of the light source may arise from improper control of driving current for amplitude dimming. For a given dimmer setting, the average optical power from the light

sources is constant. This implies that the center color of the color constellation is constant.

D. OOK Dimming

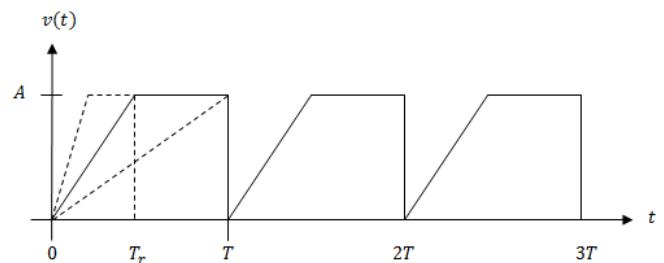
Since OOK modulation is always sent with a symmetric Manchester symbol, compensation time may need to be inserted into the data frame to adjust the average intensity of the perceived source. This process breaks the frame into subframes and each subframe can be preceded by a resync field that aids in readjusting the data clock after the compensation time. The data frame is fragmented into subframes of the appropriate length after the FCS (frame check sequence) has been calculated and FEC (forward error correction) has been applied.

E. VPPM (Variable Pulse-Position Modulation) Dimming

VPPM is a modulation scheme adapted for pulse width based light dimming and offers protection from intra-frame flicker. It does not create a color-shift in the light source that can arise from amplitude dimming because the pulse amplitude in VPPM is always constant and the dimming control is performed by the pulse width, not the amplitude. VPPM makes use of the characteristics of 2-PPM (pulse position modulation) for non-flicker and PWN for dimming control and full brightness. Bits “1” and “0” in VPPM are distinguished by the pulse position within a unit period and have the same pulse width within their respective unit periods. The non-flicker characteristic in VPPM is obtained from the property that the average brightness on bits “1” and “0” is constant. Dimming and full brightness in VPPM is achieved by controlling the “on” time pulse width. It is possible to adjust the pulse width for VPPM based on the dimming requirements. Therefore, a user can achieve the full brightness that can be provided by the light source.

III. PULSE DUAL SLOPE MODULATION

In Pulse Slope Modulation (PSM) the modulating signal changes the slope of the rising edge of the pulse but maintains a constant frequency carrier. PSM belongs to the family of pulse analog modulation techniques which offer a much improved signal-to-noise ratio performance without excessive bandwidth restriction [9]. The waveform of PSM, is shown in Figure 1.



Mishra [8], but they did not provide how to maintain the same brightness during an idle period. In this investigation a way of illumination with less flicker is provided. In PSDM the binary input bit “0” stream changes only the slope of the rising edge of the pulse within the pulse duration, keeping the slope of the falling edge fixed. The binary input bit “1” changes only the slope of the falling edge of the falling edge of the pulse keeping the slope of the rising edge fixed. Of course, the “0” and “1” can change the edge the other way around. During the idle period, the slope of the both rising and falling edges changes by the equal amount with the sign changed, i.e., the rising edge with a positive slope value and the falling edge with a negative slope value. The waveform of the PSDM signals is shown in Figure 2.

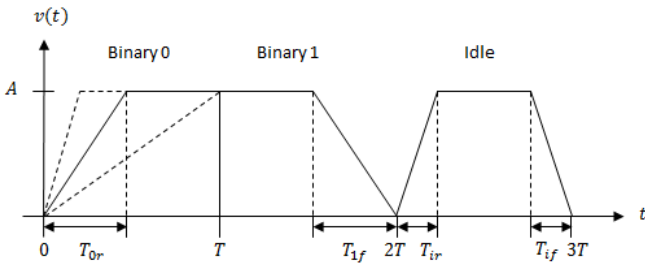


Figure 2. Pulse dual slope modulation waveforms

The magnitude of the slope of the rising edge representing “0” is equal to the magnitude of the slope of falling edge representing “1”. Or equally,

$$T_{0r} = T_{1f}. \quad (1)$$

During the idle period, to maintain the same brightness, the area of an idle symbol must be the same as the area of either “0” or “1” bit symbol during a symbol duration, assuming the brightness is exactly proportional to the voltage applied to the photodiode. This results in

$$T_{ir} = T_{if} = \frac{T_{0r}}{2} = \frac{T_{1f}}{2}. \quad (2)$$

Therefore, the slope, defined as $m = A/T_{0r} = A/T_{1f}$, can be varied depending on the modulation index. The slope of the falling edge for binary “0” and the slope of the rising edge for binary “1” should be not modulated. Bit “0” and “1” in PSDM are distinguished by the rising and falling slopes of a pulse, respectively in a unit period. Since the magnitude of the slope of rising edge which represents binary “0” is equal to the magnitude of the slope of falling edge, which represents binary “1”, hence the pulse shapes are mirror images of each other. Therefore the average brightness in bits “0” and “1” are equal as shown in the first and second pulses of Figure 2. So during data transmission there will not be any brightness discrepancy irrespective of whether bit “0” or “1” is transmitted. This satisfies the intra-frame flicker compensation. The discrepancy of the average brightness between the data transmission time and idle time results in the inter-frame

flicker. To compensate the inter-frame flicker, the idle pattern whose average brightness is equal to that of the data frame is sent during the idle time. The idle pattern proposed in this paper just does that. The slope in the idle pulse is twice the rising edge of the pulse for binary “0” (or the falling edge of the pulse for binary “1”) as shown in the third pulse of Figure 2. So the inter-frame flicker compensation is achieved in PSDM. The brightness control of the light source is necessary based on the user’s request. The light dimming can be accomplished in PSDM by changing the slope of the PSDM pulses, i.e., by controlling the rise time T_{0r} in binary “0”, the fall time T_{1f} in binary “1”, and the both rise time T_{ir} and fall time T_{if} in an idle period. When a user wants to set the brightness to a very dim level, moving the upper end of the slope to the end may not satisfy the user’s request. In this case the amplitude may be adjusted to provide more control over the brightness. This is shown in Figure 3. A minimum amplitude A_{min} must be predefined to avoid a difficulty at the detection process. Specially when the data rate is extremely or the idle period between data transmission is long, the PPM or PWM may cause a noticeable flicker. However, in PSDM a pulse changes modestly so the flicker is less noticeable than the cases in PPM and PWM.

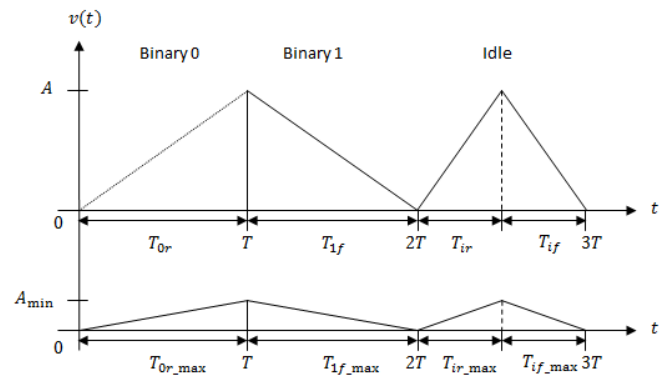


Figure 3. Pulse dual slope modulation waveforms at a dim condition

The sampling moments within a symbol interval must be chosen carefully considering the unrealistic abrupt rise at the end for binary “0” and the unrealistic abrupt fall at the beginning for binary “1”. At the receiver, the two sampled pulses within a symbol interval are simply compared. When the first pulse is greater than the second more than a marginal value δ , the receiver assumes the binary “1” was sent and when the second pulse is greater than the first by more than δ , it assumes the binary “0” was sent. When the difference between two sampled pulses is smaller than δ , the receiver assumes that it is idle. The waveforms in the detection process is shown in Figure 4.

The detection process at the receiver can be accomplished by sampling twice within a pulse symbol period as shown in Figure 5.

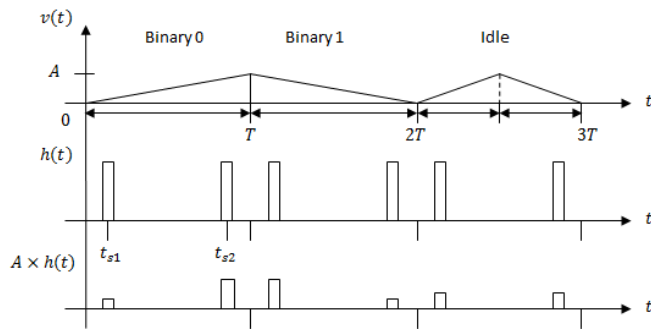


Figure 4. Waveforms at detection processes

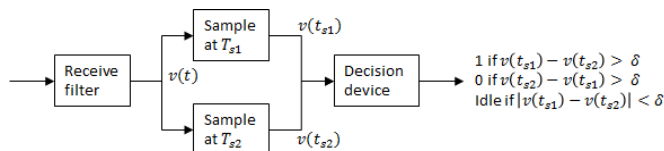


Figure 5. Block diagram of a PDSM detector

IV. CONCLUSIONS

In this investigation, a way of mitigating flicker further in VLC has been proposed. Specially when the data rate is extremely low or the idle period between data transmission is extended too long, the PPM or PWM, which are currently adopted in IEEE 802.11, may cause a noticeable flicker. However, in the proposed PDSM a pulse changes modestly so the flicker is less noticeable than in PPM and PWM. PDSM can also be applied to an extremely low light intensity. The article also has proposed a detection scheme at the receiver in PDSM, which has a simple structure.

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