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DESIGN AND ANALYSIS OF PPM BASED VISIBLE LIGHT COMMUNICATION SYSTEM WITH DIMMING SUPPORT

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Abstract

Visible light communication (VLC) is a green technology which is the replacement of the existing conventional radio frequency based indoor communication system. VLC system fundamentally comprises of a light source such as high brightness light emitting diodes (HBLEDs) that can accomplish dual function simultaneously i.e., illumination as well as data transmission. This paper presents a circuit design and analysis of PPM based VLC system and demonstrates the dimming control scheme. In this regard, front ends of the transmitter and the receiver were tested successfully by sending and consequently receiving equal width PPM frame via MATLAB. As it is known that dimming is an essential part of illumination and traditionally it is achieved by using pulse width modulation (PWM). Compared to PWM, PPM is facile to be applied since constant illumination level is easily achieved by PPM irrespective of data bits. The results show that either bits are (0000) or (1111) the illumination remained same i.e., 50%

illumination level. Moreover, the VLC system with dimming support was tested for communication having 2m range.

Keywords

Visible light communication, Dimming, Pulse width modulation, Pulse position Modulation.

1. Introduction

Visible light communication (VLC) systems are low cost and low power systems and they are facile to be installed and maintained with high data rates in contrast to wired network. Visible spectrum is preferred over RF is due to its environmental friendly behavior, regarded as green technology (Sugiyama, H. et al, 2007: Saadi, M. et al, 2013). The concept to employ the light as a communication source with the illumination is an ingenious and is not a widely commercialized technology yet (Sagotra, R., & Aggarwal, R., 2013: Rajagopal, S. et al, 2012).

In VLC, light emitting diode (LED) is used as a source of illumination and data transmission. In comparison with fluorescent and incandescent lamps, LEDs possess distinct benefits owing to its dominant properties such as fast switching, longer life time, more energy efficient, possess eye safety factor and is low cost (Saadi, M. et al, 2013: Sagotra, R., & Aggarwal, R. 2013). Recent studies show that photosynthetic rate in plants is precisely enhanced by manipulating their photoperiods. Muhammad Fahri Riadi et al. reported that Light quality affects the productivity of cucumber plants, particularly in induction of flowers. Feby Mayorazaki et al. reported that 16 h photoperiod resulted in the best quality of plants from all aspects. This shows that LED specifications are supposed to be re-adjusted for maximum energy efficiency for plant production and that why LEDs are referred as green technology ((Muhammad Fahri Riadi et al., 2015: Feby Mayorazaki et al., 2015). The function of LED is to convert electric current into light that enables it to be adopted as high speed optical transmitter. Recently high brightness (HB) white LEDs are in trend that are fabricated relying on InGa based blue and green LEDs (Tanaka, Y. et al, 2001).

Voltage and current modulations are used to generate intensity modulation (IM). There is a linear relationship between LED current and output light power. Therefore, current modulation is preferred technique. As voltage modulation experiences non-linearity that constraints the modulation range to a small value of volt and distorts the transmitted data signal. So to obtain intensity modulation across LED voltage modulation is not preferred. For this purpose there is need of linear transformation of input voltage into input current by transconductance circuit. That is implemented either by MOSFET or BJT as both the devices can operate appropriately over large current ranges and then LED is derived by this circuit (Sohail, M. et al, 2014). The proposed system makes use of BJT based trans conductance circuit in the derived circuit of LED.

The selection of modulation is one of the important factors in a VLC based OWC system for data transmission and illumination. The effects of flickering and dimming factor are also based on the adopted modulation scheme (Rajagopal, S. et al, 2012). There are several techniques which can be used to obtain modulation of light from LEDs; however, the simplest one is the IM that is utilized for data transmission. Whereas for data reception direct detection (DD) is used. There are two approaches of modulation schemes that include single carrier modulation and multi carrier modulation. The single carrier modulation schemes that are implemented in VLC are On-Off keying (OOK) with non-return to zero pulses, OOK with return-to-zero pulses, pulse width modulation (PWM) and pulse position modulation (PPM) (Ali, A. Y. et al,2014).

Though OOK is the simplest type of single carrier modulation scheme, it is sensitive towards the consequences of dimming and arises the flashing during the on and off of an LED. The transmitted data by OOK depends on the ratio of the duration of the 'on' and 'off' of an LED (Pradana, A. et al, 2015). The approach to dim an LED that relies on PWM can be interpreted as, the brightness levels can precisely be controlled by the width of the modulated signal but it cannot commercially be utilized for data transmission and it results in flickering of LED (Ntogari, G. et al, 2011: Choi, J. H. et al, 2010). PWM based transmission in VLC in combination with PPM (Pulse position modulation) is reported to be range limited i.e., 25cm (Elmirghani, J. M. H. et al, 1996).

Dimming control is the main consideration in VLC that is given more attention due to power savings and energy efficiency and can be defined as the technique of measuring the brightness of LED lights. It is focused to pursue communication, while the light source is dimmed, without being affected. So the illumination can be adjusted in an environment depending on the priority level of end user and energy is also saved by this way. Hence dimming control is focused to brighten an LED. Dimming range is a significant factor of dimming control and is the lighting brightness range of an LED (Ali, A. Y. 2014: Ma, X. et al, 2012: Stefan, I. et al, 2012).

In Pulse position modulation (PPM) a single optical pulse is transmitted per frame where L symbols exist that have M data bits mapped to one of the possible symbols where $L = 2^M$ Information (data bits) is encoded in the position of the pulse that is located in the time slot of the symbol. So that each symbol is comprised of a pulse finding its position in a single slot with $L - 1$ slots being empty. Dimming is achieved by varying the number of pulses in the symbol. Usually a guard band is sent at the end of each frame to secure from pulse dispersion and to reject inter frame interference (IFI) (Ghassemlooy, Z., & Hayes, A. R. 2003: Zeng, Y. et al, 2008).

PPM with equal width was reported for dimming by K.L. Sterckx et al. however the circuit design and the real implementation was not carried out (Sterckx, K. L., & Saengudomlert, P. 2011). This paper presents the circuit design and analysis for PPM based VLC system with dimming support. Section 2 presents the system model, comprising of the hardware and the software system design. Whereas test and analysis are shown in Section 3. Finally, conclusion and future work are the part of Section 4.

2. System Model

The proposed system design depicted in Fig. 1 mainly comprises of two parts i.e. hardware system design and software system design. In software design, PC1 is used for the data generation in the form of random bits by the software MATLAB. Afterwards the same software is used to map the bits on PPM with equal width. The PPM signal is then transmitted through audio port to the analog front end transmitter circuit. The hardware design encompasses VLC transmitter circuit and receiver circuits.

In the transmitter circuit, the LED driver circuit displays the dimming effect across LED relying on the PPM scheme with equal width square pulses so that the data is transmitted through the optical wireless channel. Furthermore for data reception, the analog front end receiver circuit comprising of photo diode (PD) and transimpedance amplifier (TIA) is used. Optical to electrical

(O/E) conversion takes place through PD. The signal received at PD experiences signal degradation due to optical channel's response. The received signal is amplified and converts the current signal into voltage signal by TIA. Finally this signal is fed to PC2 where the signal is recovered by MATLAB.

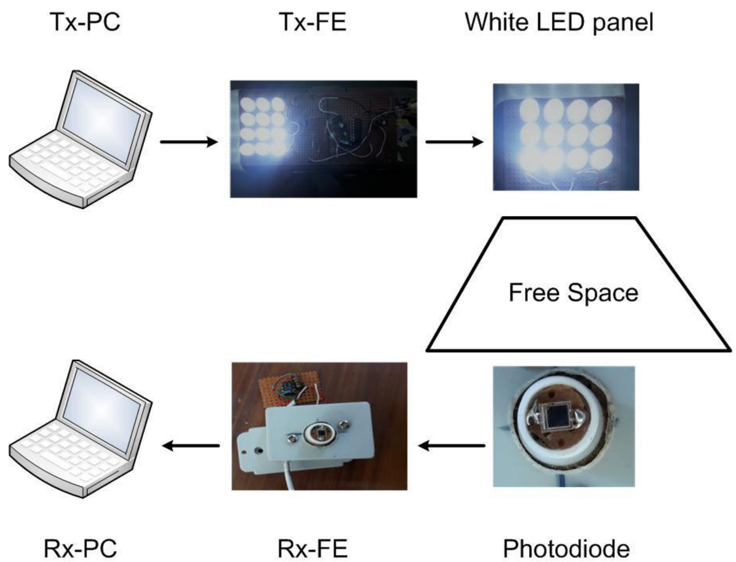

Figure 1: *Setup for PPM with equal width based on VLC with dimming*

2.1 Hardware System

The hardware setup, shown in Fig. 2, in the proposed system comprises of transmitter front end (Tx-FE) and receiver front end (Rx-FE) circuits.

2.1.1 Tx-FE Circuit Design and Analysis

Tx-FE is designed using LED model OSW57L111P from Optosupply with a maximum current of 50mA, given in its data sheets. Transmitter contains a panel of $5 \times 3 = 15$ LEDs. To drive LED panel, BJT based transconductance circuit is used. BJT model 2SC1383 with maximum collector current of 1A, from its data sheets, is selected. Fig. 2 depicts the circuit design of Tx-FE. Input voltage, applied at the base of BJT, is changed into input current by resistance R_b.

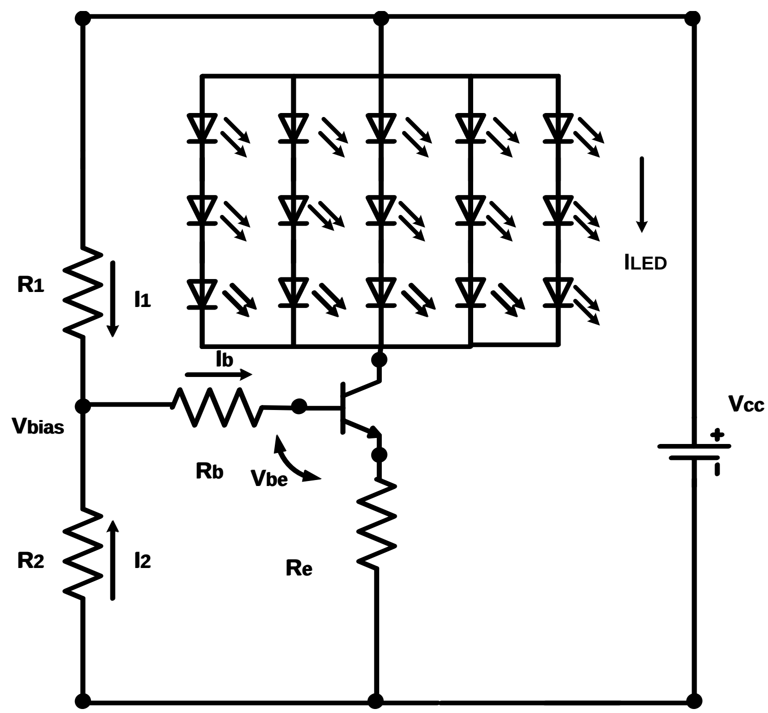

Figure 2: *Tx-FE based on TCA and LED panel*

In order to stabilize the forward current gain of the BJT current-series feedback is used. The load current is sampled by the feedback network. The transfer function *B* of the feedback network is given by,

$$B = V_f/I_{o\ =\ Ie}\, R_e/I_e = R_e \tag{1}$$

Therefore the value of R_e is needed to be adjusted.

Clearly the output current through LED is calculated by applying KVL at the feedback loop,

$$V_{in} - I_b R_b - V_{be} - I_e R_e = 0 \tag{2}$$

The current through the emitter is,

$$I_e = I_c + I_b \tag{3}$$

Since $I_c = \beta\, I_b$, (3) becomes,

$$I_b = I_e/\,\beta{+}1 \tag{4}$$

Substituting (4) in (2) yields,

$$V_{in} – I_e R_b / \beta+1 – V_{be} – I_e R_e = 0 \quad (5)$$

Using $I_{LED} = I_e$,

$$I_{LED} = V_{in}– V_{be}/ R_e+ R_b / \beta+1 \quad (6)$$

Applying KVL at the base, taking $V_b = 1/3\ V_{cc}$, according to the rule of thumb gives,

$$V_f = 1/3\ V_{cc} - V_{be} \quad (7)$$

R_e is calculated based on $I_{LED\ max}$, from (7) gives,

$$R_e = V_f/ I_{LED\ max} = 1/3\ V_{cc} - V_{be}/ I_{LED\ max} \quad (8)$$

Using $V_{cc} = 5v$, $V_{be} = 0.7v$, for LED panel $I_{LED\ max} =50 \times 15mA=750\ mA$, (8) gives,

$$R_e = 5/3-0.7/750mA=0.967/0.75=1.29\ \Omega \quad (9)$$

R_b is calculated from (1), by taking $I_{LED\ max}$, β_{max} and $V_{in\ max}$,(6) yields,

$$R_b = (\beta_{max} +1)\ (V_{in\ max} – V_{be}/ I_{LED\ max} - R_e) \quad (10)$$

Using $\beta_{max} = 500$, $V_{in\ max} = 1.7\ v$,(10) yields,

$$R_b = (500+1)\ (1.7- 0.7/0.75 – 1.29\Omega) = 21.71\ \Omega \quad (11)$$

Voltage divider bias is used and according to KVL at the input loop,

$$V_{cc} = V_{bias} + V_1 = V_{bias} + I_1R_1 \quad (12)$$

Solving (12) for I_1,

$$I_1= V_{cc} - V_{bias}/ R_1 \quad (13)$$

R_1 is fixed to be $1M\ \Omega$, fulfilling the necessary condition $I_b < I_1$, (13) gives,

$$I_1= 5- 0.7/ 1M\ \Omega \quad = 4.3\times10^{-6} A \quad (14)$$

I_b is calculated by specifying $I_{LED}\ min = 1mA$,

$$I_b = I_{LED}\, min/\beta + 1 = 1mA/ 500+1= 1.9\times10^{-6} A \qquad (15)$$

Applying KCL at the voltage divider,

$$I_1 = I_2 + I_b \qquad (16)$$

Solving (15) for I_2,

$$I_2 = 4.3\times10^{-6} - 1.9\times10^{-6} = 2.4 \times10^{-6} A \qquad (17)$$

R_2 is calculated

$$R_2 = V_{be} / I_2 = 0.7/ 2.4\times10^{-6} = 2.9 \times10^{-7} A \qquad (18)$$

Therefore by the circuit analysis the values of the parameters R_e , R_b, R_1 and R_2 are evaluated. After the implementation of the analysis, the circuit analysis is proved to be accurate. The values of the carbon resistor taken for this purpose are considered to be nearer to the calculated values in the available series of carbon resistors in lab.

2.1.2 Rx-FE Circuit Design and Analysis

In the Rx-FE, the photodiode (PD) in combination with transimpedance amplifier (TIA) is used. The output of PD is current signal that is converted into voltage signal by the TIA as shown in Fig. 3.

The specifications of the components used in the proposed design of the Rx-FE circuit are reported to be as: Photoconductive mode of operation is used here. In which an external reverse biased is applied, the output current that is measured is linearly related to the input optical power. The reverse biasing increases in proportion to the width of the depletion region with enhanced responsivity. The PD model used is BPW34S.

Inverting amplifier with the negative feedback configuration is used here with the photodiode that converts the current signal into voltage. The op amp model used here is LM6364 to design the transimpedance amplifier circuit.

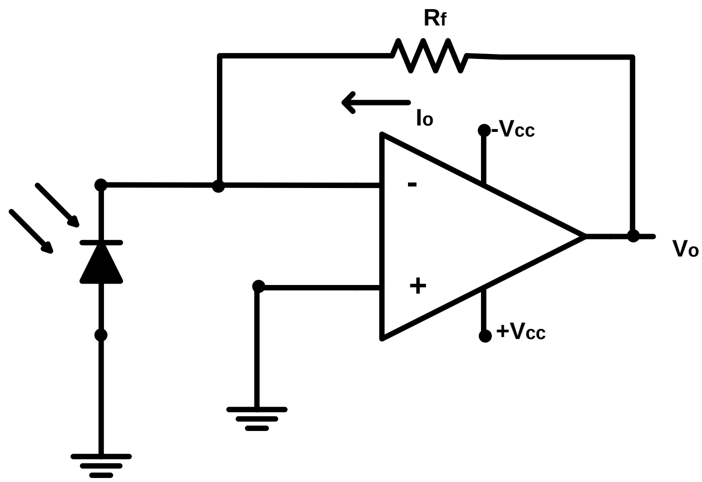

Figure 3: *Rx-FE design for proposed system*

It is known that the optical signal is converted to current signal I_p by the PD which passes through the feedback resistance R_f that is given,

$$R_f = V_o / I_p \tag{19}$$

R_f is obtained, as for audio port the output voltage drawn from op-amp is set to $V_o = 1v$ and $I_p = 2{\times}10^{-6} A$, (19) yields,

$$R_f = ½{\times}10^{-6} = 500k\,\Omega \tag{20}$$

2.2 Software System Design

The software used in this work is MATLAB, with the aid of which random data bits and PPM frame is generated. Subsequently this PPM frame is fed to the Tx-AFE via audio port. It acts as an interface so that the user can enter data in the form of audio signal that is fed to the transmitter through the audio port. The process to generate PPM in the software comprises of the generation of random bits, pulse generation and PPM frame generation.

Hence the PPM generation through MATLAB consists of the following:

- Generation of random bits
- Pulse generation
- PPM frame generation

3. Results and Discussion

In the experiment, different tests are performed. Firstly in the hardware portion, front end of the transmitter Tx-FE is tested. In order to check either Tx-FE is working properly, equal width PPM frame was generated through MATLAB and was sent to the Tx-FE.

Similarly the front end of the receiver Rx-FE was tested to ensure its working. As a consequence, this equal width PPM frame was received by the receiver. Finally, the experiment showed that the proposed hardware system is feasible for the communication purpose i.e. the data can be transmitted by Tx-FE and can be received by Rx-FE.

In this regard, 4-PPM was used and standard voltage$1V_{PP}$ is used. The following parameters were used that is given in Table 1.1.

Table 1: *List of parameters used in software design*

$\boldsymbol{f_s}$	10kHz
$\boldsymbol{T_f}$	1/10 f_s
PPM level	4-PPM
No. of bits for each frame	4 bits
Transmitted bits	10^6

Each 4-PPM frame that is expressed in terms of time frame comprises of 8 slots where either bit ‘0’ or bit ‘1’ is allocated to its assigned positions. To achieve illumination, two cases were tested. In the first case, preselected bits were (0000) and 50% illumination was achieved. As it can be seen in Fig. 4 that the PPM frame is for bits (0000).

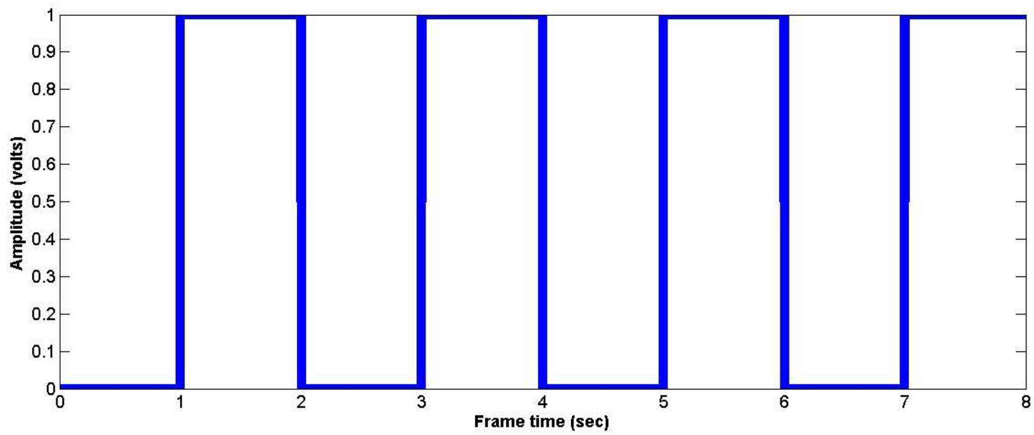

Figure 4: *Generated PPM frame by MATLAB software for preselected bits (0000)*

Whereas in the second case, preselected bits were (1111) and again 50% illumination was obtained. Which can be seen in Fig. 5 that now the bits are (1111) finding the alternate positions in the PPM frame.

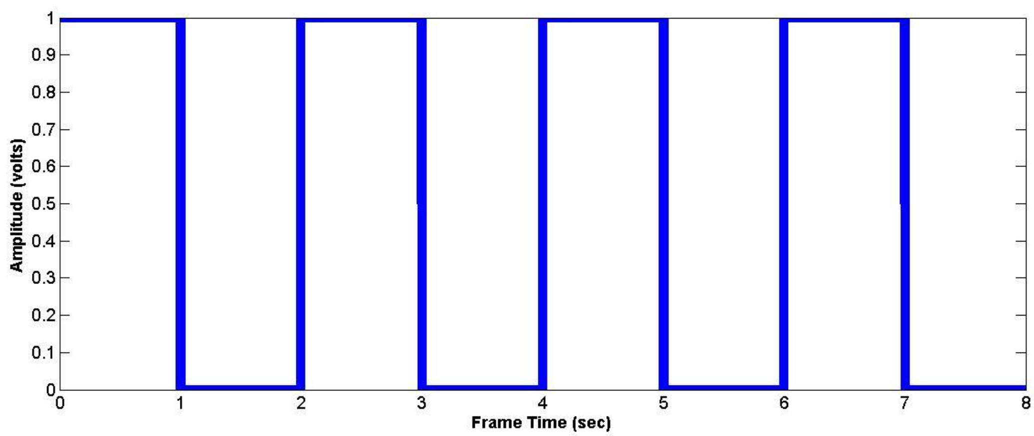

Figure 5: *Generated PPM frame by MATLAB software for preselected bits (1111)*

Therefore the above results show that PPM is comparatively a better choice than PWM as constant illumination level is easily achieved by PPM irrespective of data bits. It was experimentally shown that data bits are (0000) or (1111), the illumination remained same and it was facile to achieve dimming. As in PWM the flickering effect was present when used for dual purpose (i.e. for communication and illumination).

The proposed communication system is obviously a portable system design that provides mobility for the user. The distance between the LED and PD plays a vital role in this scenario. The communication range achieved was 2m which was earlier reported to be 20cm.

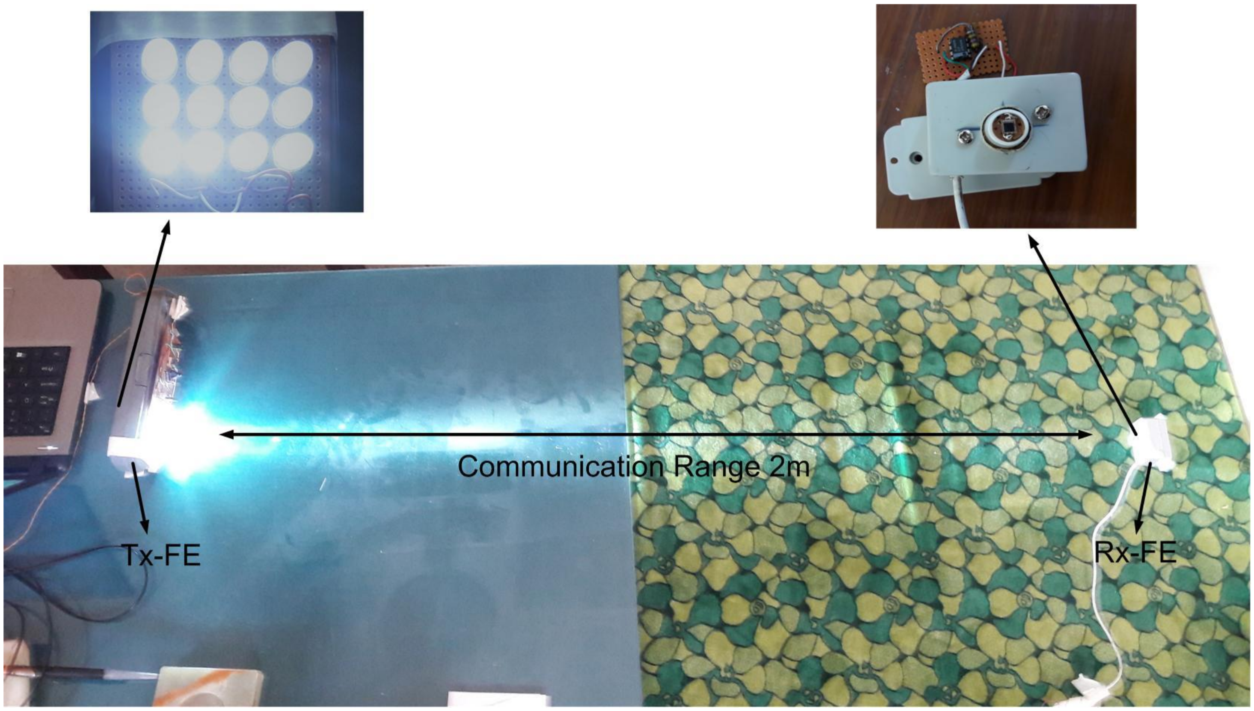

Figure 6: *Depiction of VLC based communication system with dimming*

4. Conclusion

This paper deals with the circuit design and analysis for PPM based VLC system with the dimming support. The proposed work focused on the hardware system design that has practically not been implemented yet for VLC system. In this regard for transmitter, LED driver circuit was designed and analyses were done which was comprised of BJT based trans conductance circuit with current series feedback. The front end transmitter was tested for VLC and the results successfully showed the compatibility. Consequently for receiver, photodiode based trans impedance amplifier circuit was designed and analysis were done. The receiver was tested in lab and the results revealed that the achievable transmission range was 2m that was previously reported to be 25 cm.

The second part of the investigated work dealt with the software system design. The software MATLAB was used with the aid of which equal width PPM frame was generated and was sent via audio port of one PC to another. The whole system was tested and the results display that it was suitable and facile for OWC systems. Furthermore it was shown that either data bits are (0000) or (1111), the constant illumination level was achieved i.e., 50% illumination level. Compared to PWM, where the flickering effect was reported earlier, PPM is more favorable technique. The reported design mainly finds its applications in an indoor environment. Implementation of PPM with equal width pulse in VLC with dimming support for high speeds is the ongoing research work.

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