



Channel Characterization for Visible Light Communication with the Help of MATLAB

K. Manivannan*, A. Sivanantha Raja, S. Selvendran

Department of ECE, A.C.College of Engineering & Technology,
Karaikudi, Tamilnadu, India

Abstract—LEDs are recently expected to be utilized for the next generation of indoor optical wireless communication named as Visible Light Communication or LiFi. In this paper we investigate the line of sight Optical Wireless Channel characterization of Visible Light Communication by practically measuring a White LED's illuminance values. A comprehensive mathematical model is also derived and simulated in MATLAB® to investigate the power distribution, attenuation and Beam Divergence of the White LED under study.

Keywords—Lux, Illuminance, White LED, power distribution, attenuation, beam divergence, VLC, OWC

I. INTRODUCTION

New generation LED lighting has more advantages such as long life, high tolerance to humidity, low power consumption and minimal heat generation than existing fluorescent and incandescent lighting. And moreover 70% of the wireless voice and data traffic take place in an indoor environment. A reliable, high bandwidth, low cost solutions are particularly required to meet the indoor wireless communication requirement. LEDs have been used to transmit data at higher rates over a short-range OWC link [1]-[3]. Visible light communication (VLC) [4] has such a promise by making use of LED lighting infrastructure for wireless communication. The LEDs can be used for dual propose of illumination and data communication. Increasing interest in the research community is witnessed on physical layer issues for high speed VLC systems [5]-[9].

On using the White LED for communication, it is necessary to define the luminous intensity and transmitted optical power because luminous intensity is used for expressing the brightness of an LED and the transmitted optical power indicates the total energy radiated from an LED [10]. The most common link configurations for indoor Optical Wireless Communication (OWC) system are the line-of-sight (LoS) and non line of sight (NLoS) characteristics. The LoS based OWC system help in understanding the channel characteristics. In this paper we study the characteristics of LoS characteristics of the White LED such as power distribution, attenuation and beam divergence through practically measured values of LED illuminance and characterized through MATLAB® simulations. Here we use the commercial LED of Tekhol® make and measurements are done with HTC Lux meter (Model: LX103) to measure the illuminance of LED.

The rest of the paper is organized as follows. Section II describes the room setup for VLC and the practical measurement procedures. Section III describes the characterization of the white LED channel with the help of MATLAB® and power distribution, attenuation and beam divergence are investigated. Finally the conclusion is given in the last section IV.

II. PHYSICAL MODEL

A. The room setup and LED placement

The proposed indoor white LED lighting setup for characterization calculation is shown in Figure1(a). Since we consider line-of-sight LED characterization for optical wireless channel, a white LED was installed at the center of the ceiling. In order to get better illumination of room, 4 pieces of LEDs were closely packed. The size of the room was 5m x 5m x 3m as given in Figure1(b) and the measuring distance between LED and the Lux meter was kept at the distance of 2.4m as the receiver was placed on a table as a working plane.

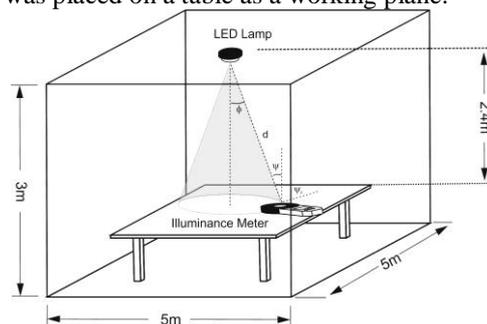


Figure 1. (a) The room setup

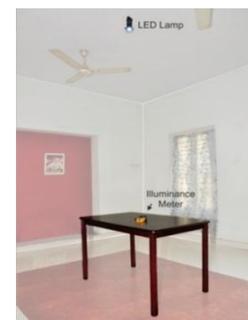


Figure 1. (b) The room setup

The illuminance was measured in lux meter. The center illuminance was measured by placing the meter exactly beneath the LED where it was normal to the light radiated by the LED and further readings were measured for various heights. The horizontal illuminance variations were measured at different angular distances on the plane. The White LED and Lux meter specifications are shown in Table 1.

TABLE I LED AND LUX METER SPECIFICATIONS

| | | |
|-------------------|-----------------|---------------------------|
| LED | White LED Model | TH-3737TZ-4X5730 |
| | Power Output | 2.4 W/pcs |
| | Lumens | 120-150 lm |
| | View angle | 120° |
| Illuminance Meter | Model | LX-103 |
| | Range | 0~200000 Lux / 0~20000 FC |
| | Resolution | 0.01 Lux / 0.01 FC |

III. WHITE LED CHANNEL CHARACTERIZATION

A. Power Distribution

The distribution of illuminance of LED has a Lambertian radiation pattern. The Lambertian emission means that the light intensity emitted from the source has a cosine dependence on the angle of emission with respect to the surface normal. Following function for an optical link [11], the luminous intensity in angle ϕ is given by:

$$I(\phi) = I(0) \cos^m(\phi) \tag{1}$$

Where $I(0)$ is the center luminous intensity of the LED, ϕ is the angle of incidence, m is the order of Lambertian emission and is given by the semi-angle at half illuminance of the LED $\Phi_{1/2}$ as:

$$m = - \ln(2) / \ln(\cos \Phi_{1/2}) \tag{2}$$

A horizontal illuminance / intensity at a point (x,y) and the received power at the receiver, and assuming no optical filter and optical concentrator are used, are given by :

$$H(0) = \begin{cases} I_{hor} = I(0) \cos^m(\phi) / d^2 \cdot \cos(\psi) & (3) \\ \frac{(m+1)A}{2\pi^2} \cos^m(\phi) \cos(\psi), & 0 \leq \psi \leq \psi_c \\ 0, & 0 \geq \psi_c \end{cases} \tag{4}$$

Where A is the physical area of detector in a Photo Detector, here the illuminance meter sensor diameter is taken as detector diameter. d is the distance between transmitter and receiver, ψ is the angle of irradiance and ψ_c is angle of field of view (FOV) at the receiver. The received power P_{Rx} is given by

$$P_{Rx} = P_{Tx} H(0) \tag{5}$$

Where P_{Tx} is the transmitted optical power of LED.

B. Practical Measurements

In order to measure the illuminance, at first the measurement was taken at a distance of 2.4m and then the height was reduced step by step and corresponding lux values were measured. The measured values and calculated received power were shown in Table. 2. Since the receiver i.e., Lux meter was placed at normal to the incident light of the LED, the angle of incidence was considered as zero.

TABLE II MEASURED LUMINANCE AND POWER VALUES (VERTICALLY)

| Illuminance (lux) | Height (h) (meters) | Distance between LED to receiver (d) (meters) | Angle of irradiance ψ (deg) | Power at the receiver (w) | Power at the receiver (dB) |
|-------------------|---------------------|---|----------------------------------|---------------------------|----------------------------|
| 21.4 | 2.4 | 2.4 | 90 | 3.87E-05 | -44.1197 |
| 50 | 1.52 | 1.52 | 90 | 9.66E-05 | -40.1523 |
| 76.5 | 1.2 | 1.2 | 90 | 0.000155 | -38.0991 |
| 138 | 0.9 | 0.9 | 90 | 0.000275 | -35.6003 |
| 390 | 0.53 | 0.53 | 90 | 0.000794 | -31.0010 |
| 1401 | 0.283 | 0.283 | 90 | 0.002785 | -25.5512 |

Measurements were taken horizontally over the surface and the calculated power distribution values are shown in Table.3.

TABLE III MEASURED LUMINANCE AND POWER VALUES (HORIZONTALLY)

| Illuminance (lux) | Height (h) (meters) | Distance between center to receiver (meters) | Distance between LED to receiver (d) (meters) | Angle of incident ϕ (deg) | Angle of irradiance ψ (deg) | Power at the receiver (w) | Power at the receiver (dB) |
|-------------------|---------------------|--|---|--------------------------------|----------------------------------|---------------------------|----------------------------|
|-------------------|---------------------|--|---|--------------------------------|----------------------------------|---------------------------|----------------------------|

| | | | | | | | |
|------|-----|-------|----------|--------|--------|----------|----------|
| 21.4 | 2.4 | 0 | 2.4 | 0 | 90 | 3.87E-05 | -44.1197 |
| 20.3 | 2.4 | 0.304 | 2.419177 | 7.18 | 82.82 | 3.75E-05 | -44.2571 |
| 18.5 | 2.4 | 0.608 | 2.475816 | 14.14 | 75.86 | 3.42E-05 | -44.6569 |
| 15.8 | 2.4 | 0.912 | 2.567439 | 20.78 | 69.22 | 2.96E-05 | -45.2895 |
| 13 | 2.4 | 1.216 | 2.690475 | 26.85 | 63.15 | 2.45E-05 | -46.1025 |
| 10.1 | 2.4 | 1.520 | 2.840845 | 32.32 | 57.68 | 1.97E-05 | -47.0459 |
| 8.2 | 2.4 | 1.824 | 3.01 | 37.235 | 52.765 | 1.56E-05 | -48.0659 |
| 6.5 | 2.4 | 2.128 | 3.21 | 41.562 | 48.438 | 1.21E-05 | -49.1636 |
| 4.2 | 2.4 | 2.432 | 3.42 | 45.379 | 44.621 | 9.41E-06 | -50.2626 |

C. MATLAB Simulation

For obtaining the illumination Lambertian and power distribution models over the plane, MATLAB® programs were used. The various parameters needed for simulation are listed in Table. 4. The viewing angle of the receiver was 120 °, the semi-angle at half power is taken at 60 °. The 4 pieces of 2.4 w LEDs produced approximately 358 lumens, and they gave 7W of total optical power and that was taken as the transmitted power of LED.

TABLE IV SIMULATION PARAMETERS

| | | |
|----------|--------------------------------|----------------------------|
| Room | Size | 5 m x 5 m x 3 m |
| Source | Location of LED | 2.5 m, 2.5 m, 3 m |
| | Semi angle at half power | 60 ° |
| | Transmitted power | 7 W |
| | Centre luminous intensity | 21.4 to 1401 lx (measured) |
| Receiver | Receiver plane above the floor | 0.6 m |
| | Receiver active area | 1.5 cm ² |
| | Half Angle FOV | 70 ° |

Figure 2 shows the illuminance distribution over the room of size 5 m x 5 m x 3 m with LED. Simulations of practically obtained values were verified with various values of heights through the MATLAB® program. For the evaluation purpose randomly picked values of heights, 0.53 m, 0.90 m, 1.52 m and 2.4 m were simulated and from the plot their peak power values at those heights were -31.01 dB, -35.61 dB, -40.16 dB and -44.12 dB respectively. The simulated plots for the distribution of received power at various heights of 0.53 m, 0.90 m, 1.52 m and 2.4 m are shown from Figure 3 to Figure 6.

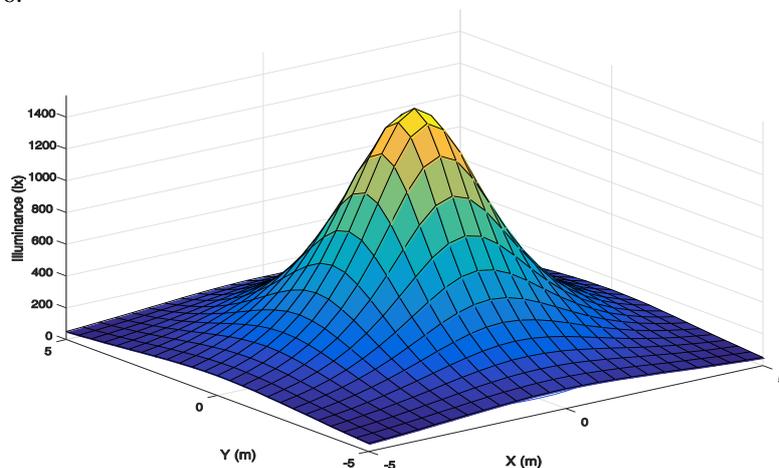


Figure 2. Distribution of illuminance simulated in MATLAB

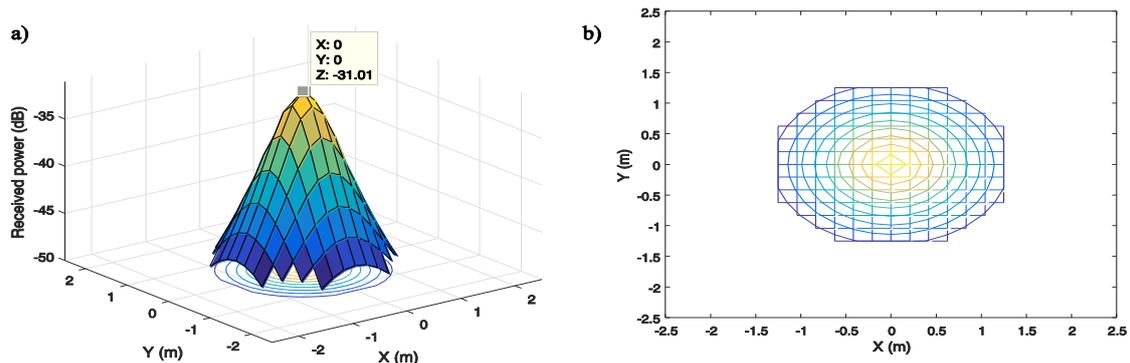


Figure 3. Distribution of received power and obtained contour plot with the height (h) = 0.53 m

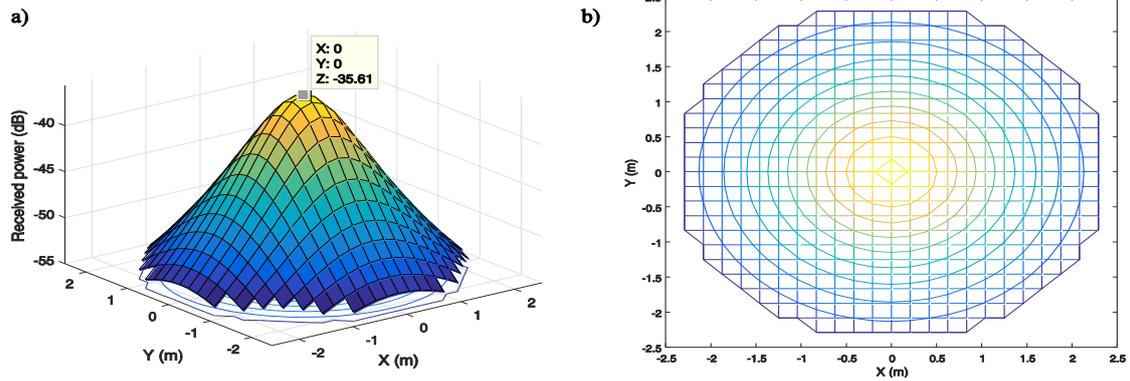


Figure 4. Distribution of received power and obtained contour plot with the height (h) = 0.90 m

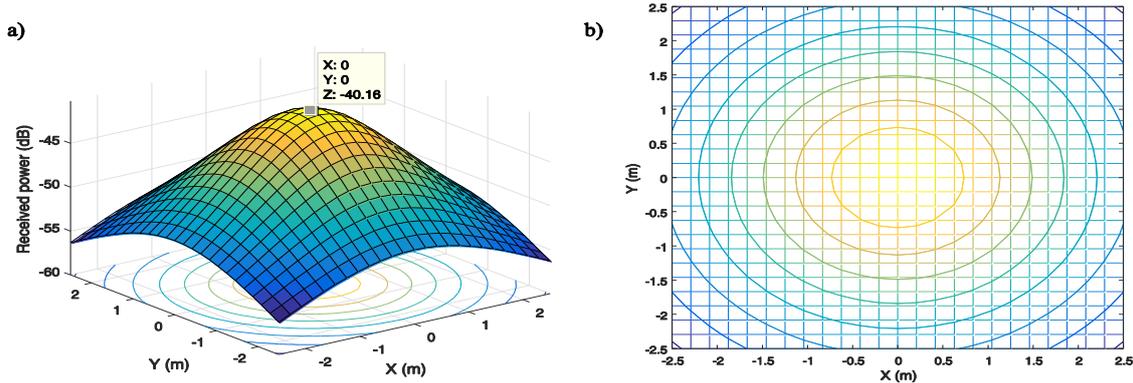


Figure 5. Distribution of received power and obtained contour plot with the height (h) = 1.52 m

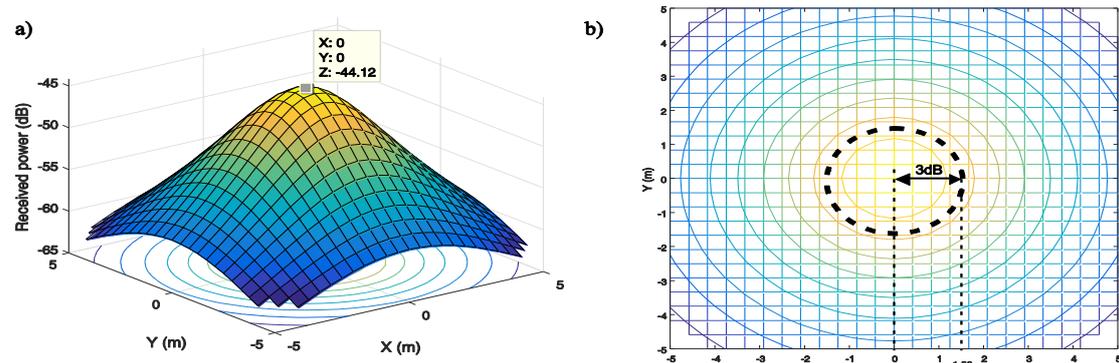


Figure 6. Distribution of received power and obtained contour plot with the height (h) = 2.4 m

D. Attenuation and Beam Divergence

i) Attenuation:

Received power vs distance curve is plotted from the values of Table 2 and is shown in Figure 7(a) and Figure 7 (b) shows the received power vs distance from the center at the distance of 2.4 m from the values obtained from Table 3. From the Figure 7(b), the full width half maximum (FWHM) obtained at -3 dB position. From Figure 6 and 7 (b), the half power from that of the center of the cell was 1.52 m and they clearly showed the coverage area of the particular LED. From Figure 7(a), slope of the attenuation line was calculated and the atmospheric attenuation was 8 dB/m.[12]

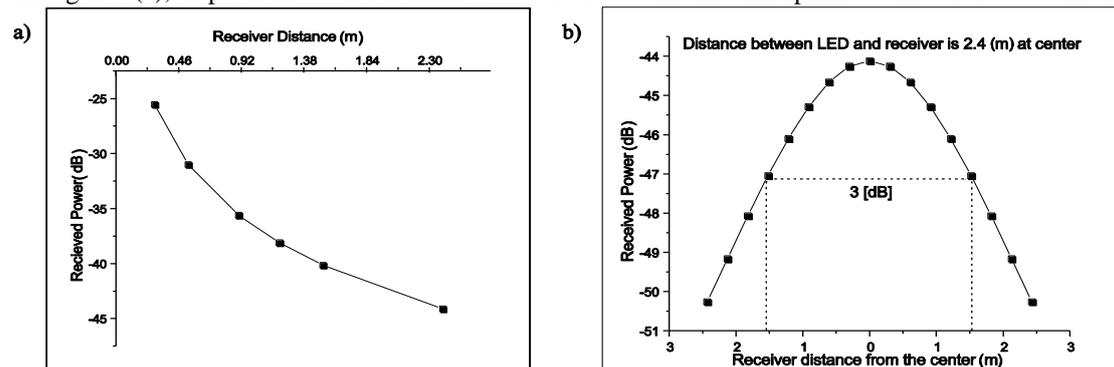


Figure 7.(a)Received power vs Distances for various heights, (b) Received power vs Distances from the center at 2.4m

ii) *Beam divergence:*

The far field condition of the LED light beam can be calculated by the beam divergence angle. The beam divergence of an electromagnetic beam is an angular measure of the increase in beam diameter or radius with distance from the optical aperture from which the electromagnetic beam emerges. The beam divergence, Θ , is given by [13]

$$\Theta = 2 \cdot \arctan \left(\frac{D_f - D_i}{2l} \right) \quad (5)$$

Where D_f is far field diameter, D_i is the diameter of optical aperture the l is the distance between these points. To calculate the beam divergence, the FWHM of the LED foot print is taken as D_f i.e. 3.04 m., D_i is taken from the LED aperture as 0.07 m, the distance between the LED and receiver (l) is 2.4 m and substitution of these values in equation (5) results the beam divergence angle Θ as 63.5°.

IV. CONCLUSION

In this paper, we have modeled, measured and simulated the received power distribution for a white LED using a Lux meter. MATLAB® program also helped further to investigate the measured values. From the investigation we found a practical way of analyzing the characteristics of a LED suitable for Optical Wireless Communication. From our studies, we obtained two significant results such as the attenuation of free space channel which was approximately 8 dB/m and the beam divergence of 63.5°. These results can be used for further research in this area in order to make use of this White LED for Visible light communication.

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