Effect of LED emission cross-section in indoor visible light communication systems

By:

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INTRODUCTION

- The visible light communication (VLC) refers to the communication technology which utilizes the visible light source as a signal transmitter, the air as a transmission medium, and the appropriate photodiode as a signal receiving component.

- optical wireless technologies provide a high level of security and a low level of interference without the need for government regulations to impact frequency usage.

OBJECTIVES [1/2]

1. This project concentrate on the effects of LED emission cross-sections on VLC systems.

2. Present a simple LED model using a non-circular quasi-elliptic emission cross-section To show that the emission cross-section affects the illumination and communication performance

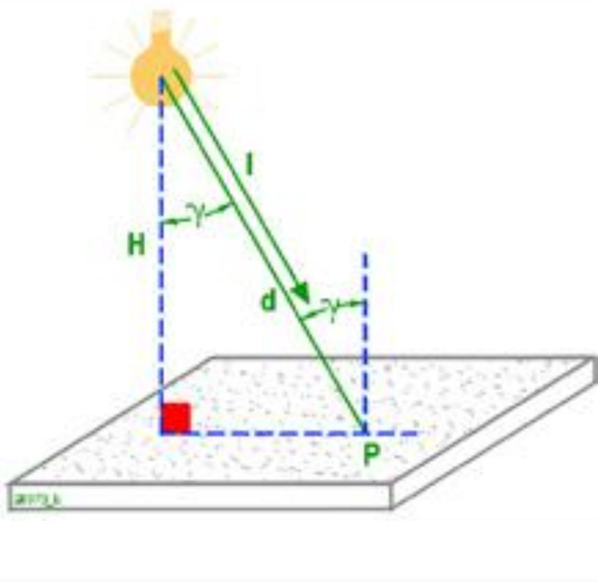
CROSS SECTION EFFECT

- The LEDs with a quasi-elliptic emission cross-section provide less fluctuation in the illumination and optical power distribution at the receiving plane. However, the RMS delay spread increases and subsequently the maximum data rate decreases for the quasi-elliptic emission cross-section LEDs.
- The single transmitter VLC system is found to support at least 17 and 24Mb/s for circular and quasi-elliptic emission cross-section LEDs.
- The four-transmitter VLC system is found to support at least at 30 and 33 Mb/s for circular and quasi-elliptic emission cross-section LEDs for the entire receiving plane, respectively

SYSTEM MODEL[1/5]

- A typical 5 m× 5 m× 3 m office room is assumed in the model. The VLC link is assumed to be a line-of-sight with the receiver.

- It is assumed that the LED lamps are installed at a height of 2.7 m from the floor, and the receiver is placed at the height of 0.85 m. Therefore, the distance from the LED lamps to the receiving plane is 1.85 m.



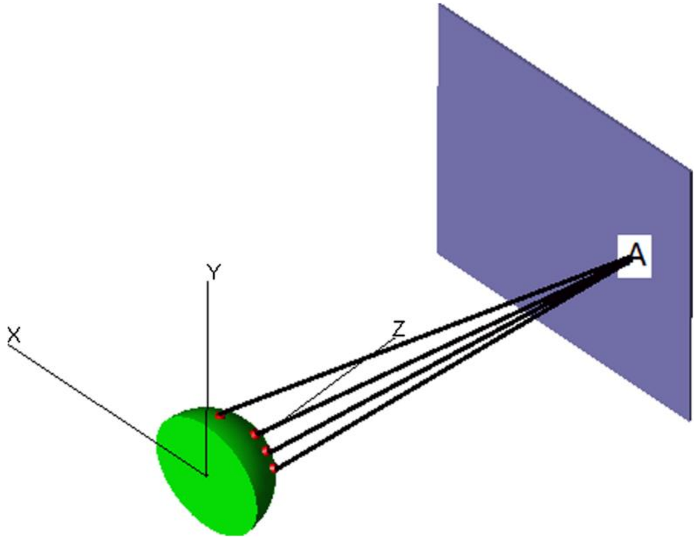
SYSTEM MODEL[2/5]

- We will simulate two cases: one-transmitter and four-transmitters.
- We make several assumptions for the simulation. Sun light and other ambient lighting are assumed to be negligible with an appropriate optical filtering and indoor environment.

- The centre luminous intensity for each LED is set at 410 cd. In the case of the LED group with a circular emission cross-section, the semi-angle at half power is assumed to be 30°, since several commercial LEDs have a value of around 30°.

SYSTEM MODEL[3/5]

- We present a simple model of a LED with a quasi-elliptic cross-section based on the combination of two LEDs with circular emission cross-sections.
- The target is a surface perpendicular to the z direction, from the centre of the two-LEDs array.



SYSTEM MODEL[4/5]

- The equation that determines the distance between two LEDs at a surface perpendicular to the z direction from the center of the two-LEDs array is:

$$d0 = \sqrt{\frac{4}{m+3} z} \qquad , \qquad m = \frac{-\ln(2)}{\ln[\cos(\theta_{1/2})]}$$

where m is related to the semiangle at half power, θ1/2.

Our simulation environment (z=1.85 m, d0=1.0 m, θ1=2 = 30°) ,it is easy to find an equivalent LED model with a non-circular quasi-elliptic emission cross-section.

SYSTEM MODEL[5/5]

- Using the propsed valued in the previous model, and by using different values of distance between two LEDs (d0) at different semiangle at half power($\theta_{1/2}$), we have the below results:

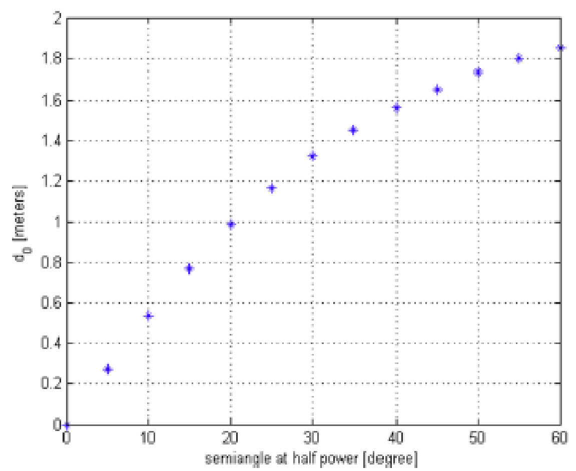
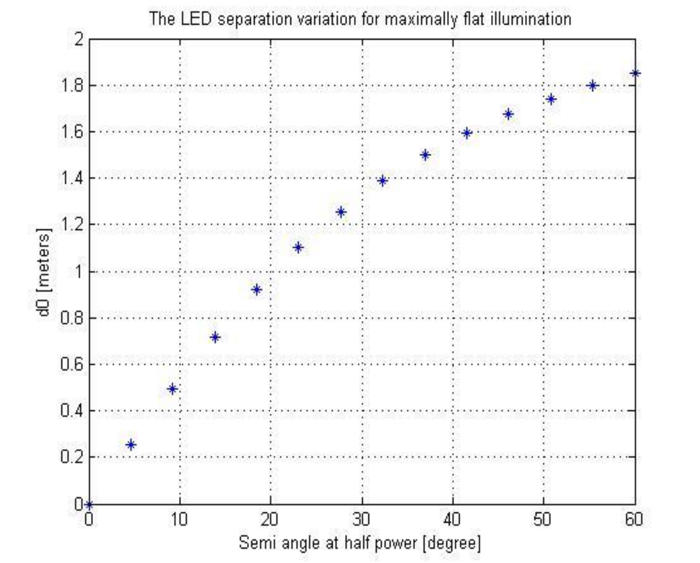


Figure 1 The LED separation variation for maximally flat illumination.



Paper Result

Our Result

MODULATION TECHNIQUE[1/3]

- Current major ways of modulation technology for VLC including:
  - On-off keying (OOK).
  - pulse position modulation (PPM).
  - digital pulse interval modulation (DPIM).
  - Orthogonal Frequency Division Multiplex (OFDM).
  - and colour-shift keying (CSK) with frequency modulation.
- OOK, PPM and DPIM don’t partition the frequency of visible light , it transmits data by turning the light source “on” and “off”. However, its data transfer rate is limited by the bandwidth of a VLC system and it is used only in low data rate systems.

MODULATION TECHNIQUE[2/3]

- In order to solve the limitation of data rate caused by long rise and fall time of light emitting diodes, m-ary return-to-zero optical pulse amplitude modulation (MRZOPAM) is proposed for improving the bandwidth efficiency of indoor visible light communication.
- MRZOPAM Properties:
  - Used for indoor short distance VLC.
  - White LED used for illumination.
  - The illumination intensity of lighting source is strong, so the signal-to-noise ratio of a receiver is high in an indoor short distance.

MODULATION TECHNIQUE[3/3]

- MRZOPAM is a bandwidth-efficient modulation based on OOK and PAM.
- It uses the control of LED light illumination intensity (amplitude), and it also supports dimming control in the transmitting process.
- Theoretical analysis shows that MRZOPAM modulation can be used to achieve higher bandwidth efficiency without sacrificing the symbol error rate and bit error rate performance of an indoor VLC.
- *For Example:* at the same conditions, MRZOPAM can provide 1.47 times bandwidth efficiency than that of OOK, 3.5 times than that of digital pulse interval modulation and 5.9 times than that of PPM.

PRINCIPLE OF MRZOPAM[1/4]

- For any integer M>2, in an MRZOPAM modulation system, all the M messages can be denoted as: mi, i = 1, 2, …, M. Illumination intensity Ai at the ith waveform can be expressed as:

$$A_i = a_{BS} + (m_i + 1) a_{slot}$$

Where:

a_{BS} is a tabular values depends on the illumination intensity symbol.

a_{slot} is the illumination intensity between adjacent MRZOPAM waveforms.

- If the high level duration of Amax is t0, or in general high level duration ti of illumination intensity Ai can be expressed as:

$$t_i = \frac{a_{BS} + M a_{slot}}{a_{BS} + (m_i + 1) a_{slot}}$$

PRINCIPLE OF MRZOPAM[2/4]

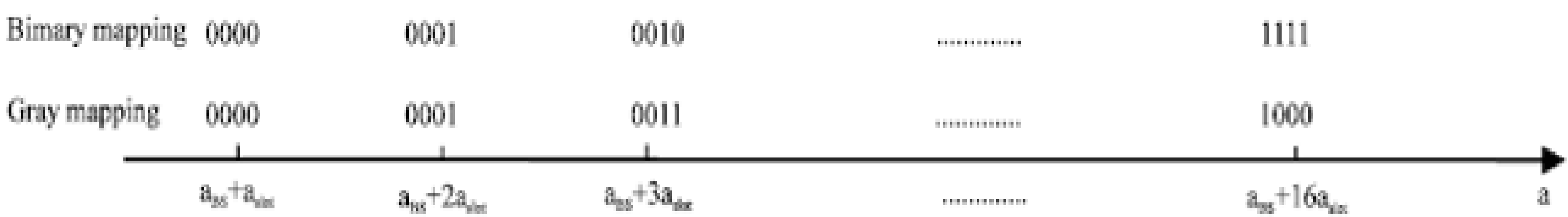
- From the previous equations, the ith transmitted waveform Si(t) can be expressed as:

$$S_i(t) = \begin{cases} a_{BS} + (m_i + 1)a_{slot} & , 0 \le t < t_i \\ 0 & , t_i \le t < T \end{cases}$$

where, T is the duration of MRZOPAM's waveform

PRINCIPLE OF MRZOPAM[4/4]

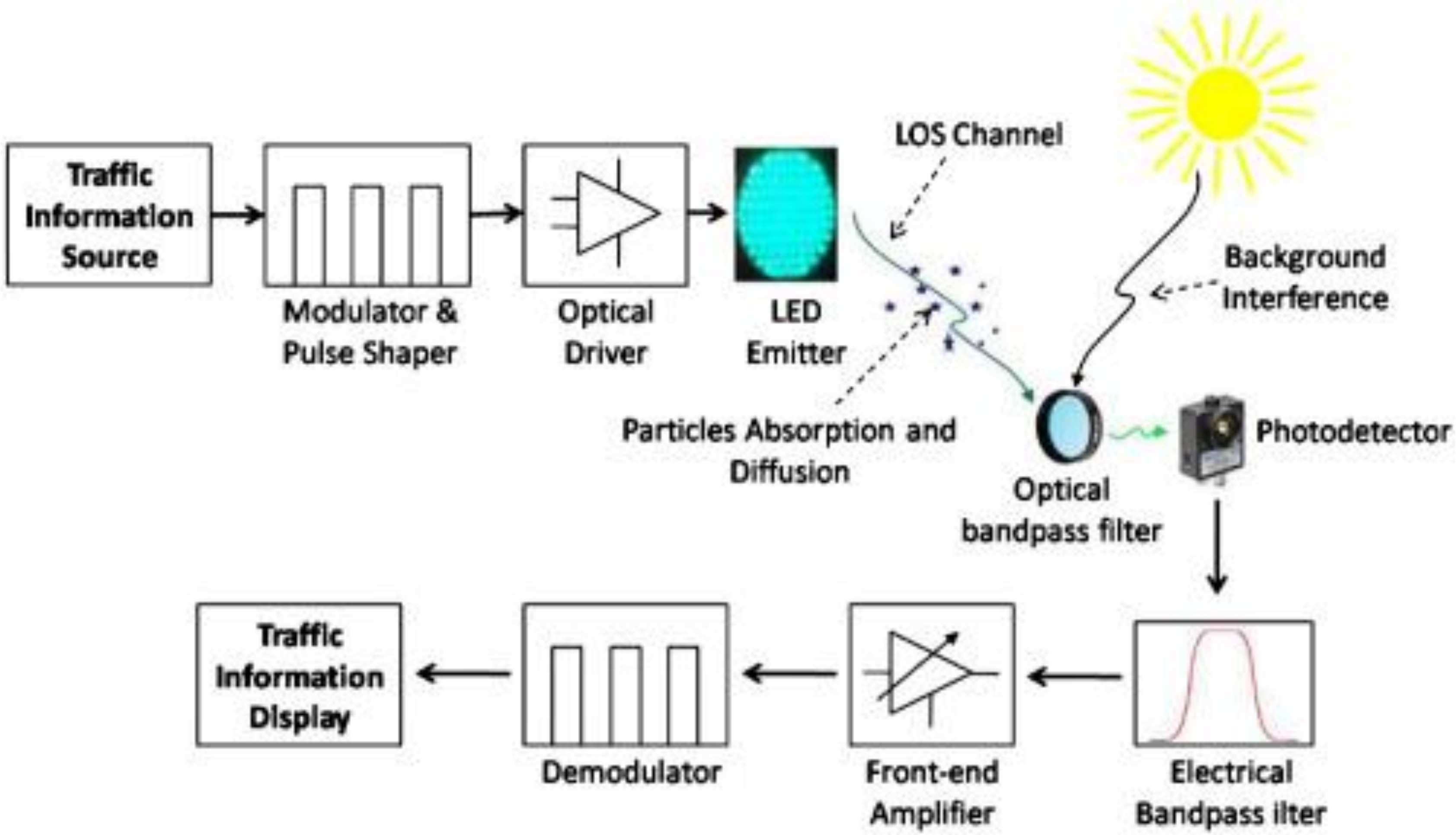
Signal space diagram for 16-ary return-to-zero optical pulse amplitude modulation (RZOPAM) signaling with binary and gray mapping.



DEMODULATION [1/2]

- At the receiving end:
  1. The voltage signal which is proportional to the light intensity.
  2. Linear photosensitive device.
  3. signal is sampled by an analog-to-digital converter (ADC).
  4. Matched-filter and an amplifier circuit.
  5. The value of sampled voltage is input in the decision circuit to obtain the demodulated data.
- Let the sampled voltage value of the decision circuit B_X, the symbol decision depends on a Maximum Likelihood (ML) method to get the source data.

DEMODULATION [2/2]



PERFORMANCE ANALYSIS

1. Bandwidth efficiency:

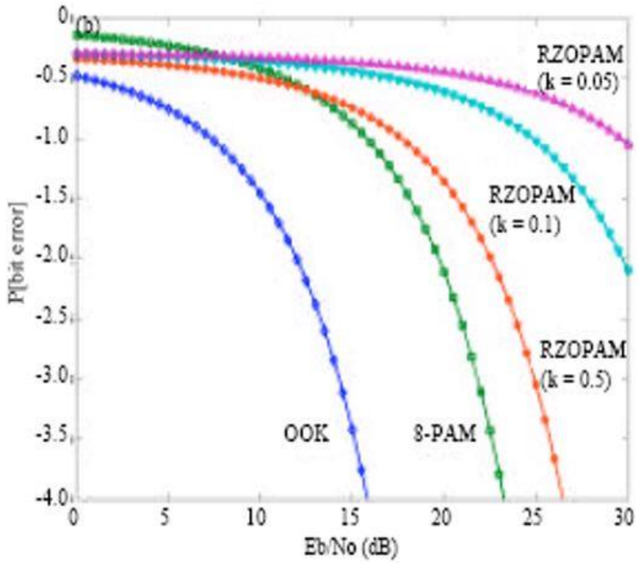
- If the bandwidth of a VLC system is limited, parameter r can be defined to describe the bandwidth efficiency which is the ratio of bit rate of signalling scheme to bandwidth.
- Let k = a_{slot}/a_{BS}, the bandwidth efficiency of MRRZOPAM can then be expressed as:

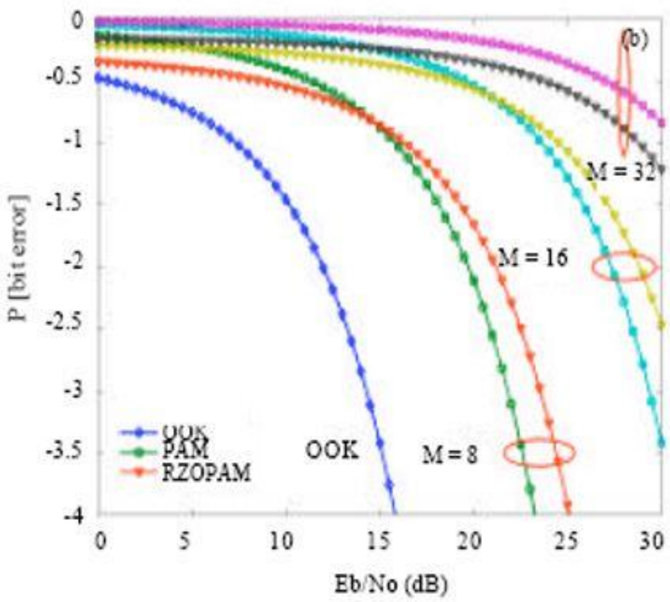
$$r_{MRZOPAM} = \frac{log_2 M}{\frac{1+MK}{K+1}+1} = \frac{b}{\frac{1+2^b K}{K+1}+1}$$

2. Error Probability:

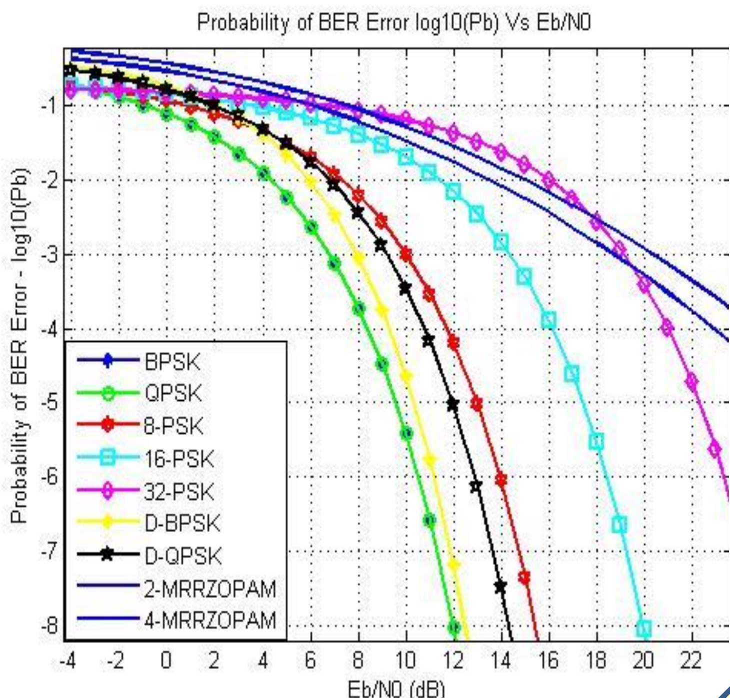
Because MRZOPAM is an improved PAM, reference can be made to the error probability of PAM and the average symbol-error probability of MRZOPAM can thus be expressed as:

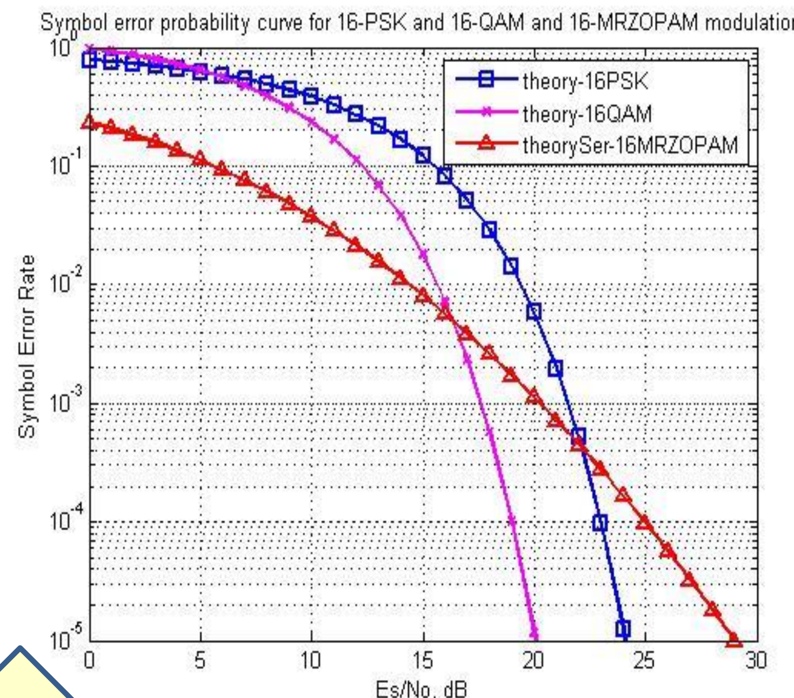
$$P_{e=}\frac{(M-1)}{M}Q[\sqrt{\frac{K^2}{K(M+1)(K+1)+(K+1)^2+\frac{K^2}{6}(M+1)(2M+1)}\frac{Eb}{N_0}}]$$





Paper Result


Probability of BER Error log10(Pb) Vs Eb/N0
Probability of BER Error - log10(Pb)
Eb/N0 (dB)
BPSK
QPSK
8-PSK
16-PSK
32-PSK
D-BPSK
D-QPSK
2-MRRZOPAM
4-MRRZOPAM


Symbol error probability curve for 16-PSK and 16-QAM and 16-MRZOPAM modulation
Symbol Error Rate
Es/No, dB
theory-16PSK
theory-16QAM
theorySer-16MRZOPAM

Our Result

PERFORMANCE OF MODULATION SCHEMES FOR INDOOR VLC SYSTEMS

Modulation scheme	Bandwidth efficiency	Power required	Dimming control	Flicker mitigation	Complexity of data process
OOK	medium	medium	No	No	simple
PPM	low	low	No	No	complex
VPPM	low	medium	Yes	Yes	complex
DPPM	low	low	No	No	medium
DPIM	low	low	No	No	medium
DH-PIM$_2$	low	low	No	No	medium
DAPPM	medium	medium	No	No	medium
PAM	High	High	No	No	medium
MRZOPAM	High	medium	Yes	Yes	medium

1. Root mean square delay spread

- Root mean square delay spread can be interpreted as the difference between the time of arrival of the earliest significant multipath component (typically the line-of-sight component) and the time of arrival of the latest multipath components. The RMSD value provide an estimate for a kind of normalized delay time due to multiple reflection.

$$\tau_{RMS} = \sqrt{\overline{\tau^2} - (\bar{\tau})^2},$$

$$\bar{\tau} = \left(\sum_{i}^{M} P_{d,i} t_{d,i} + \sum_{j}^{N} P_{r,j} t_{r,j} \right) / P_T.$$

$$\overline{\tau^2} = \left(\sum_{i}^{M} P_{d,i} {t_{d,i}}^2 + \sum_{j}^{N} P_{r,j} {t_{r,j}}^2 \right) / P_T.$$

PERFORMANCE PARAMETERS[2/11]*

- By assuming M direct paths from the transmitter to a specific receiver and N reflection path to the same receiver, the total power of the received optical signal P_T calculated as

$$P_T = \sum_{i}^{M} P_{d,i} + \sum_{j}^{N} P_{r,j}$$

- Where $P_{d,I}$ is the received optical power at the of the direct light at i-th point and $P_{r,j}$ is the received optical power of the reflected light at the j-th point

PERFORMANCE PARAMETERS[3/11]*

- The flow chart to calculate RMSDS

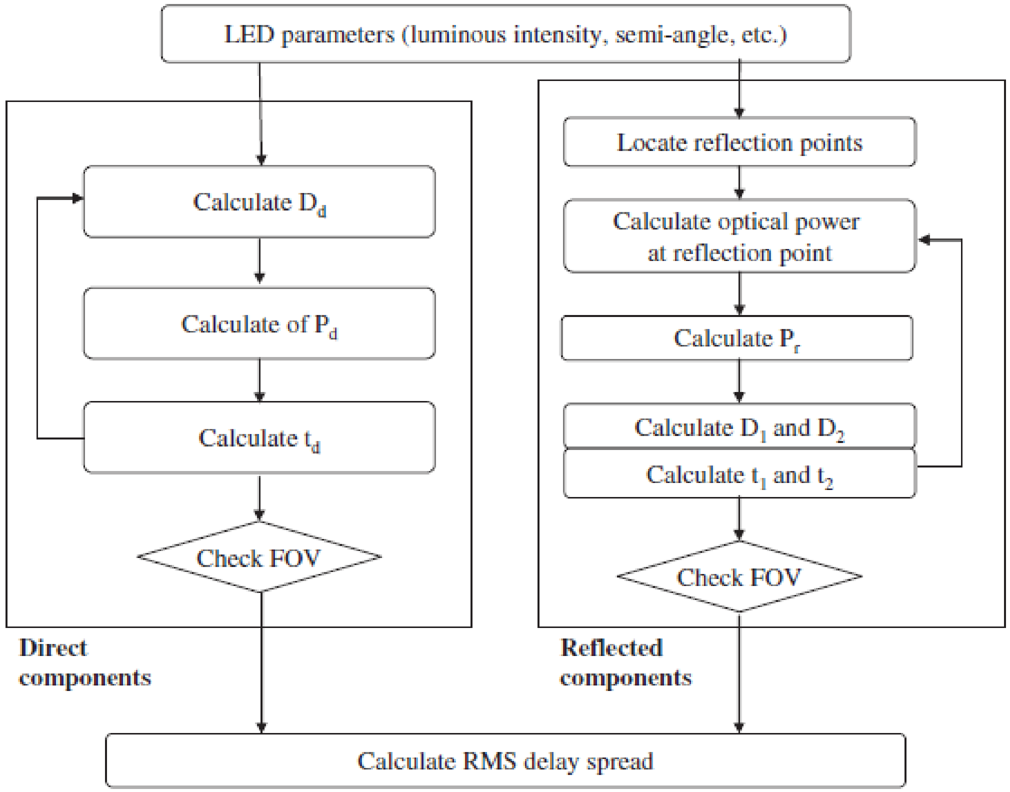
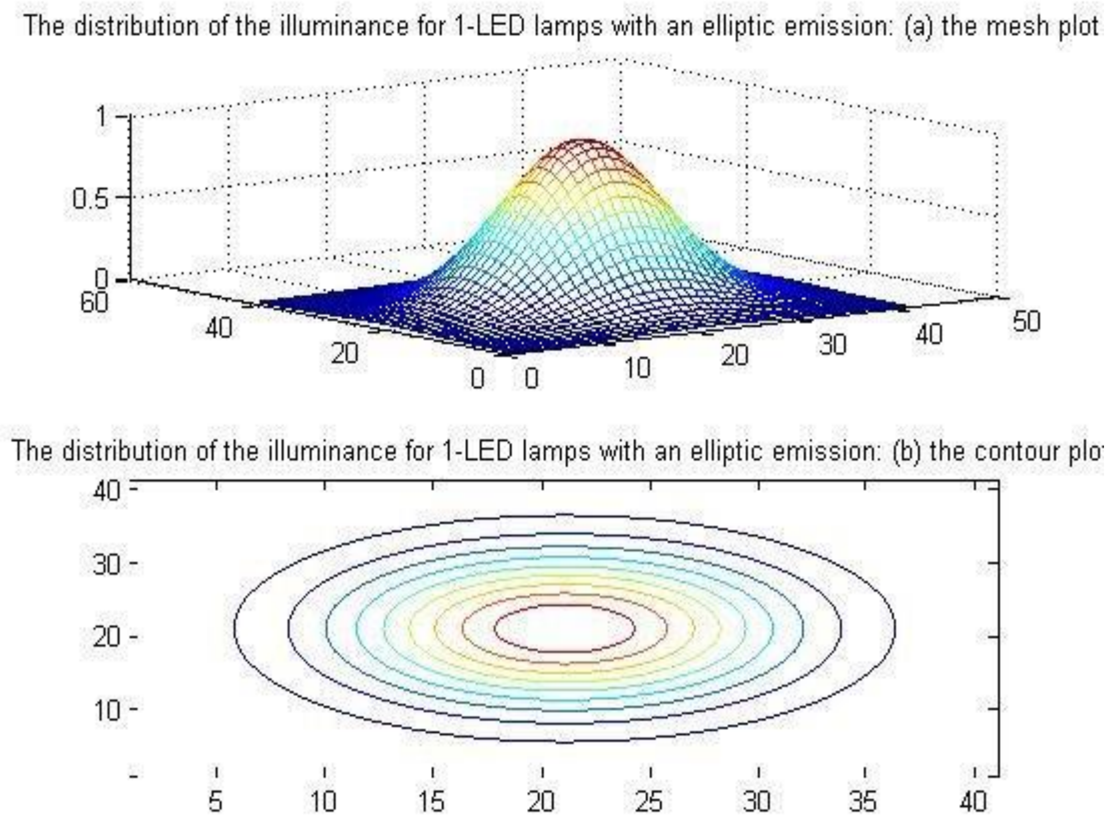


Figure 4 The flow chart used for calculating the RMSDS.

- The distribution of the illuminance for 1 led lamp with an elliptic emission

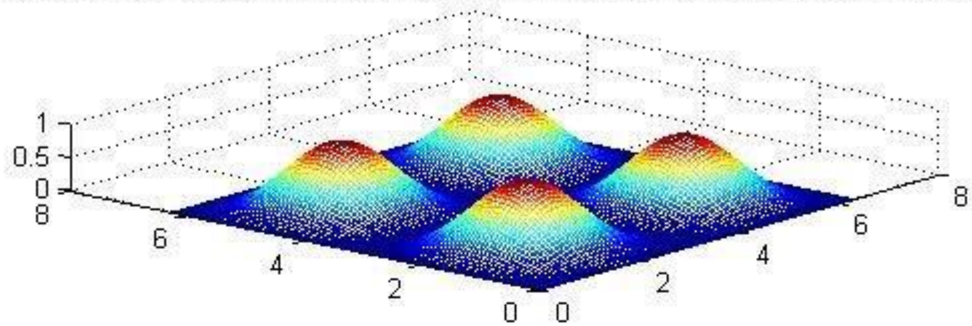


PERFORMANCE PARAMETERS[5/11]*

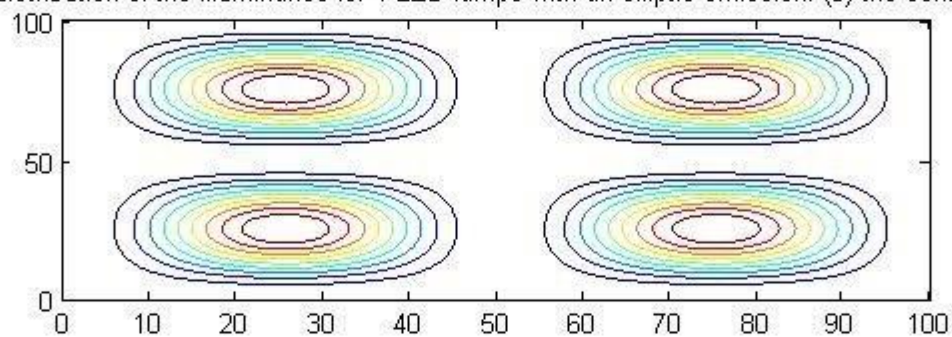
- It can be observed that the transmitter with quasi elliptic emission cross section give less fluctuation in the horizontal illuminance, and therefore the quasi elliptic emission cross section transmitters are superior to those with circular emission from view point of illumination.
- In the single transmitter case the minimum RMSDS for the non-circular quasi elliptic is 0.1620ns which is larger than found for the circular emission 0.0040ns
- This show that the non circular quasi-elliptic emission provide a wider illumination than the circular emission thereby providing generating more reflection component at the receiver

- The RMSDS values ranges from from 0.3110 to 3.1886ns for the circular emisssion and from o.3030 to 2.9868 ns for the noncircular emission. The minimum RMSDS for quasi elliptic emission is slightly larger than that found in the circular emission , this is because ther is more chances for light to reach the receiver from the circular emission

The distribution of the illuminance for 4-LED lamps with an elliptic emission: (a) the mesh plot

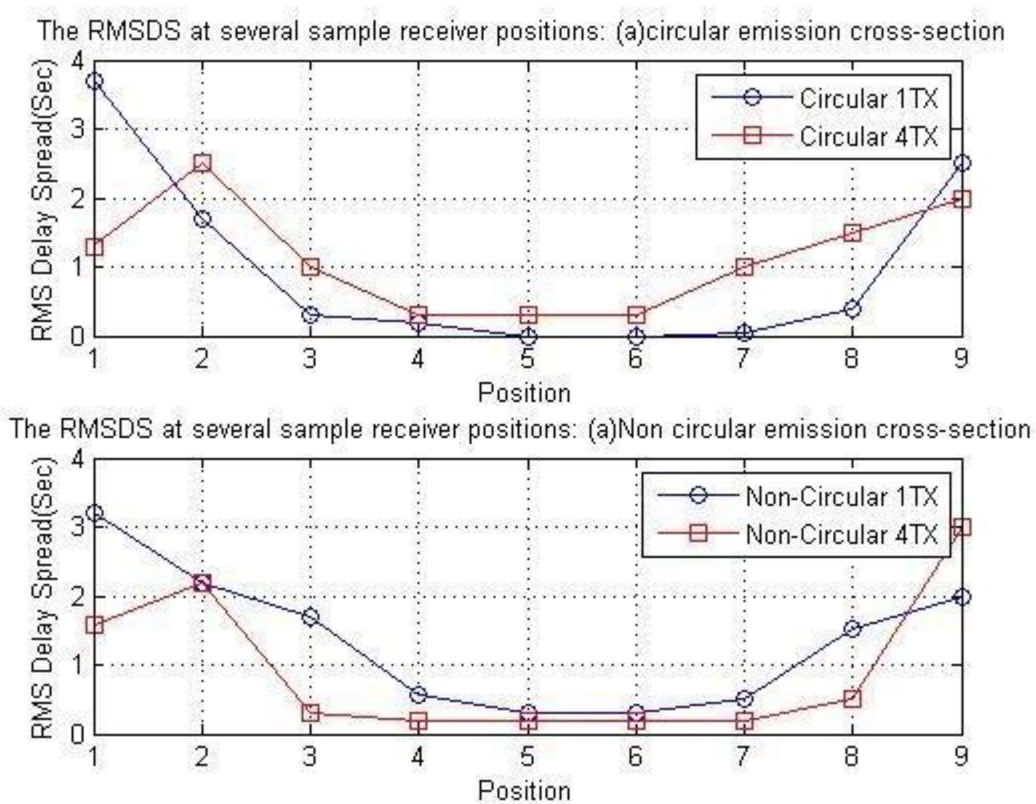


The distribution of the illuminance for 4-LED lamps with an elliptic emission: (b) the contour plo



PERFORMANCE PARAMETERS[7/11]*

- The RMSDS at several point of the sample receiver positions for circular and non circular emission cross section



2. Illumination distribution uniformity

(IU): the ratio of the maximum to minimum received power levels in an indoor optical wireless communication system, This provides the difference between the maximum and minimum optical power values from all of the calculation points.

- This only calculates two values (maximum and minimum), so it does not provide the information regarding how uniform the received optical power , Therefore, (IU) method is proposed as a factor used to determine the horizontal illuminance variations, IU is therefore defined as the ratio of the difference between the maximum and minimum values of the horizontal illuminance to its average value.

$$IU = \frac{\{E_{i,j}\}_{max} - \{E_{i,j}\}_{min}}{\mu_E}$$, *Where:*

$\{E_{i,j}\}_{max}$: the maximum value of the horizontal illuminance.

$\{E_{i,j}\}_{min}$ is the minimum value of the horizontal illuminance on the receiving surface.

N is the total number of elements in the receiving surface.

μE denotes the mean of the illuminance and is given by:

$$\mu_E = \frac{1}{N} \sum_{i,j} E_{i,j}$$

N: The total number of elements in the receiving surface is given as N = Nx × Ny. Nx: the number of calculation points along the x-axis.

Ny denotes the number of calculation points along the y-axis.

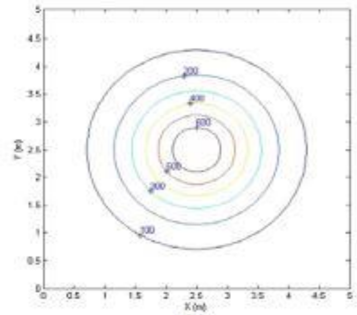
In the simulations, Nx and Ny were set to 25.

PERFORMANCE PARAMETERS[10/11]

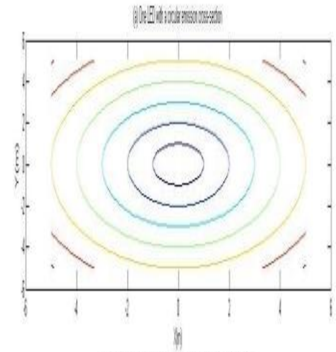
- The following Figures show the variation of the IU in a dB scale for the different number of transmitters.
- The IU depends on the shape of emission cross-section and the semi-angle at half power.
  - When the semi-angle at half power is small, the difference due to the shape of emission cross-section is large.
  - With large semi-angles at half power the effect of the number of transmitters is weak.
  - The IU for one transmitter is smaller than that found for four transmitters in the case of large semi-angle at half power.

PERFORMANCE PARAMETERS[11/11]

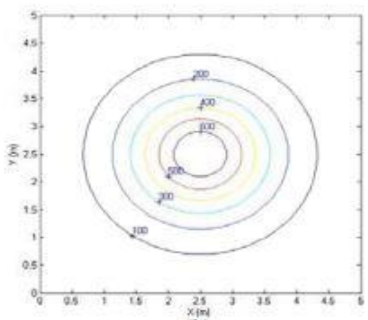
The horizontal illuminance contour plots:



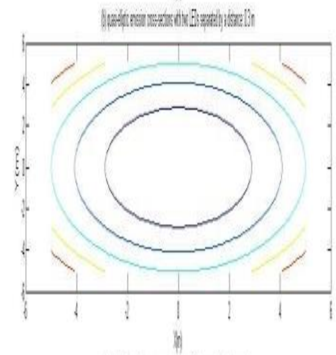
(a)



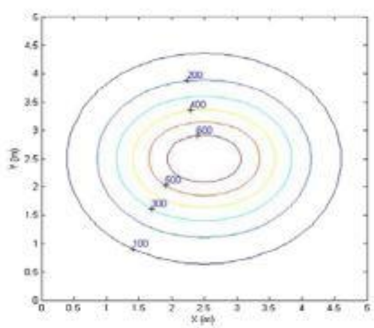
(a) one LED with a circular emission cross-section.



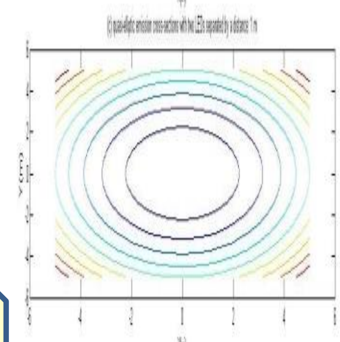
(b)



(b) quasi-elliptic emission cross-sections with two LEDs separated by a distance: d = 0.3 m.



(c)



(c) quasi-elliptic emission cross-sections with two LEDs separated by a distance:d =1.0 m.

Paper Result **Our Result**

CONCLUSION[1/1]

- The simulation for the distribution of illuminance, received optical power and RMSDS for a non circular quasi elliptic emission cross section and circular emission shows that:
  1. Emission cross sectional effect, affects the illumination and communication performance.
  2. The led with non circular quasi-elliptic emission shows less fluctuation in illumination and optical power.
  3. MRZOPAM increase subsequently limiting the DR compared with the other modulation methods.

Thank you

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