



EFFECTS OF VARYING TRANSMITTER HALF POWER ANGLE IN VISIBLE LIGHT COMMUNICATION

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ABSTRACT

Visible light communication (VLC) involves sending and receiving information using light as carrier to transmit the information from sender to receiver. One of the most important parameters of a transmitter in a VLC system is the semi angle at half power which is also referred to as the transmitter half power angle. Varying it could affect the amount of light or optical power received at the receiver and depending on the configuration of the transmitters. This can lead to loss of some part of received power. This work investigates how such variation in half power angle can affect average received power by considering separate transmitter arrangements/configuration that can be adopted for VLC based on same number of these transmitters. Six separate arrangements of six transmitters were considered in a line of sight (LoS) indoor VLC scenario. The results were achieved by varying the half power angle between a minimum of 10° and a maximum of 80° . The result showed that different levels of received power were attained at different half power angles for each different transmitter configuration. For instance at a low angle of 10° , the third configuration had an average received power of 2.8139mW while fourth configuration had an average received power of 2.6700mW which implies the third configuration has a better performance. At a high angle of 80° , average received power for third configuration was 1.2207mW and it was 1.0672mW for the fourth configuration showing that the third configuration still performs better. The third configuration generally outperformed all the other ones. The fifth configuration had a good average received (2.8120mW) at low angle of 10° but it gradually became poorer (1.1782mW) at higher angles of up to 80° in comparison to other configurations which indicates this configuration does not perform well at higher half power angles. The findings of the work signified that changing the transmitter configuration can cater for power losses that maybe encountered as a result of varying the transmitter half power angle in a VLC system without giving up so much on uniformity of distribution of the light.

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1.0 Introduction

Visible light communication (VLC) is a new paradigm that could revolutionize the future of wireless communication (Rehman et al., 2019). VLC is expected to address the tension between continuously increased demand of capacity and currently limited supply of radio-frequency spectrum resource (Hu et al., 2021). There is a gradual extension towards the visible light portion of the Electromagnetic (EM) spectrum which can be utilized for communication in order to complement existing Radio Frequency (RF) communication. More than 70% of communication originates from indoor as shown by previous studies (Ergul et al., 2015). With VLC expected to have its best application in indoor scenarios, it will form an integral part of the next generation wireless communication system.

VLC contains huge communication capacity and activates a new spectrum resource entirely which is the biggest value of this technology (Albayati, 2019). VLC refers to the communication technology which utilizes the visible light source (usually LED) as a signal transmitter, free space as a transmission medium, and the appropriate photodetector (PD) as a signal receiving component (Lee, 2011). The light source will serve a dual usage of illumination and communication which further makes VLC attractive.

VLC technology is useful mainly due to superior capacity of transmission and information rate, no health hazards and low power utilization (Jha et al., 2017). These advantages and many more, makes VLC a suitable candidate to form an integral part of communication systems in the near future. This work seeks to look into how average received power can be affected by the type of arrangement of transmitters and also variation in the transmitter half power angle in VLC.

Previous studies have looked into transmitter configuration, received power distribution, average received power, effects of changing transmitter/receiver parameters and so on. Khalifeh et al., (2019) investigated the effect of LEDs position for an indoor environment on the performance of a VLC system where the authors improved the distribution of received power and peak power by first reconfiguring their 4 LED arrangement and then adding another LED to take care of drawbacks. Similarly, Mahfouz et al., (2018) did a study where they compared between a proposed arrangement of 16 LEDs and two other 16 LEDs arrangement in terms of a number of communication parameters. They also checked out the effect of varying the transmitter half power angle from 20° to 70° on the received power of their proposed model. From the results, it was deduced that increasing the half power angle reduces the received power and vice versa.

A research was conducted by Gismalla and Abdullah, (2019) on optimization of received power and SNR where they proposed a novel indoor attocells network configuration using 5 LEDs in order to improve coverage against 1 and 4 LED placement. They also investigated effects of altering transmitter half power angle on optical received power where their proposed model was observed to be poorer at very low angles but outperformed the 4 LED model at higher angles. In Verma and Pandey, (2022), researchers looked into the impact of LED half power angle and configurations of transmitters on the distribution pattern of power received in indoor VLC. They considered a varying number of transmitters configuration from 2×2 up to 9×9 array, they also performed optimization to find suitable half power angle. Their findings indicated that 20° half power angle when used with a differential optical receiver has a good power level with less noise at a good uniformity and is optimal for the 9×9 array configuration

From the reviewed literatures, it is obvious that both transmitter configuration and transmitter half power angle affect received power distribution. Hence, it is important to consider them jointly in order to have a comparative basis whereby an optimal arrangement of transmitters that has best received power performance can be found relative to the half power angle. Therefore, this work will investigate jointly the effect of varying the half power angle and changing the transmitter configuration, considering equal number of transmitters (6 LEDs) to see the effect on average received power and observe the one with the best performance.

2. Materials and Methods

The emission pattern of the transmitters follows Lambertian model and the Lambertian radiant intensity $R(\phi)$ is given as (Shaaban and Faruque, 2020);

$$R(\phi) = \frac{(m_l+1)}{2\pi} \cos^{m_l}(\phi) \quad (1)$$

Where m_l is the Lambert's mode number and ϕ (degrees) is the angle of irradiance from LED.

The relationship between m_l and transmitter half power angle $\Phi_{1/2}$ (degrees) is;

$$m_l = \frac{-\ln(2)}{\ln(\cos \Phi_{1/2})} \quad (2)$$

The receiver is modeled as a physical area, A_a (m^2) collecting light at an angle of incidence, ψ (degrees) which gives rise to effective communication area A_c (m^2) with a field of view (FOV) ψ_c .

$$A_c(\psi) = \begin{cases} A_a \cos\psi & \text{for } 0 \leq \psi \leq \psi_c \\ 0, & \text{for } \psi > \psi_c \end{cases} \quad (3)$$

For the communication link, only the line of sight component is considered for less complexity since it offers the strongest contribution to received power at the receiver. The geometry for such a link is given in Figure 1, the LED is the transmitter and the photodetector (PD) is the receiver.

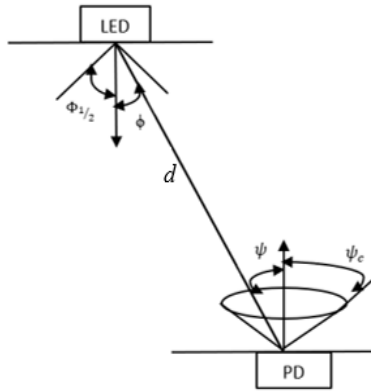


Figure 1: Line of sight (LoS) link geometry for VLC (Li et al., 2018)

The channel dc gain $H_{los}(O)$ of the LoS link is given as (Vatansever and M. Brandt-Pearce, 2017);

$$H_{los}(O) = \begin{cases} \frac{(m_l+1)}{2\pi d^2} A_a \cos^{m_l}(\phi) \cos(\psi), & \text{for } 0 \leq \psi \leq \psi_c \\ 0, & \text{elsewhere} \end{cases} \quad (4)$$

Where d is distance between transmitter and receiver.

If optical concentrator $G(\psi)$ and optical filter $T(\psi)$ are employed, then $H_{los}(O)$ is defined by;

$$H_{los}(O) = \begin{cases} \frac{(m_l+1)}{2\pi d^2} A_a \cos^{m_l}(\phi) T(\psi) G(\psi) \cos(\psi), & \text{for } 0 \leq \psi \leq \psi_c \\ 0, & \text{elsewhere} \end{cases} \quad (5)$$

The received power P_r (mW) is given by $P_r = P_{total} H_{los}(0)$ (6)

Where P_{total} is transmitted power in mW

and for the 6 LED sources, it is written as $P_r = \sum_{i=1}^6 P_{total} H_{los}(0)$ (7)

The average received power is $P_a = \frac{\sum_{n=1}^{625} P_r}{625}$ (8)

where n is individual receiving point in the receiving plane.

A standard ISO specified office size dimension of $L_x \times L_y \times L_z = 5m \times 5m \times 3m$ was considered as the communication environment.

Six different arrangement of 6 LEDs were selected for this work. All the arrangements are given in Figure 2. The half power angle $\Phi_{1/2}$ was varied in steps of 10° from 10° to 80° . This was done for all the transmitter arrangements and separate results were obtained for different $\Phi_{1/2}$ and for different transmitter arrangement. A receiving plane is formed in simulation to serve as the receiver with 625 different receiving points selected for less computation time.

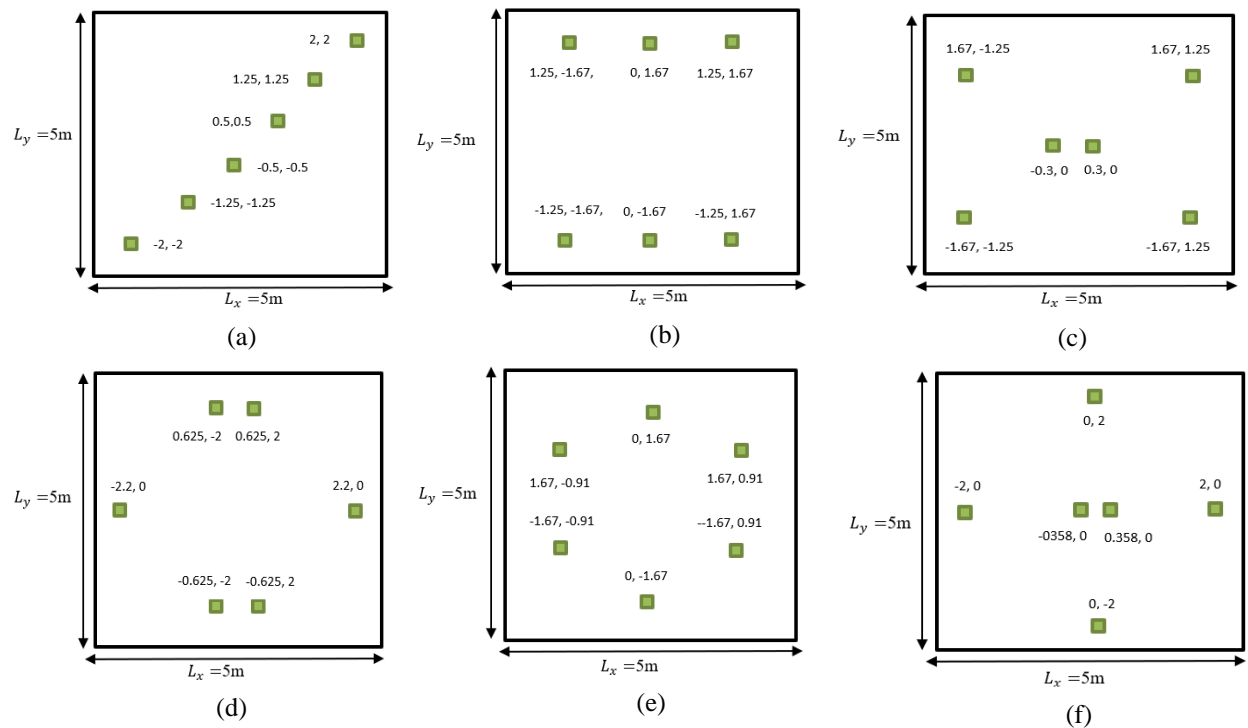


Figure 2: LED transmitter configuration on the ceiling in (x, y) coordinate format for six LEDs
 (a) First configuration (b) second configuration (c) third configuration (d) fourth configuration
 (e) fifth configuration (f) sixth configuration

3. Results and Discussion

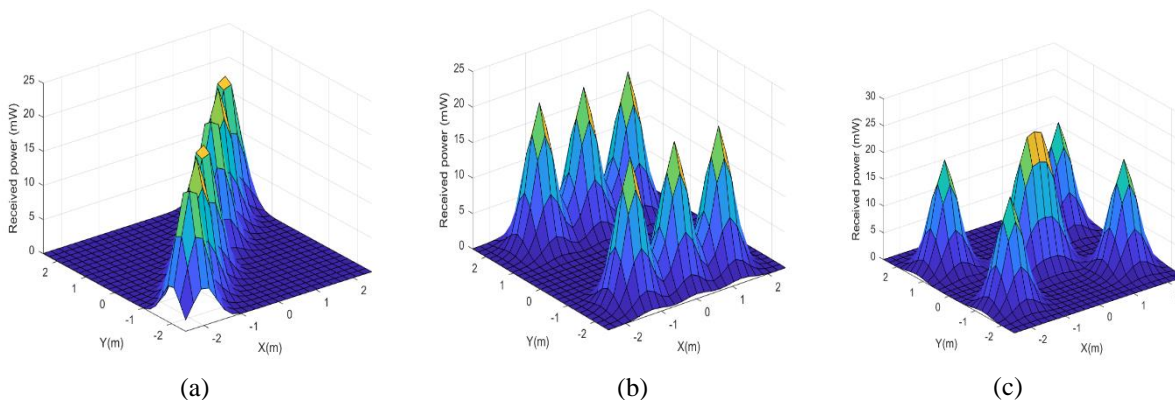
The results of this work are presented in Figures 3 to 5 and Table 2. The results were obtained through a simulation on MATLAB r2018a version. The simulation parameters are given in Table 1.

Table 1: Simulation parameters

1.	Transmitted power	20mW
2.	Receiver FOV	70°
3.	Room size	5m × 5m × 3m
4.	Receiver height	0.85m
5.	Number of LEDs per lighting source	50 × 50
6.	Area of detector	0.0001m ²
7.	Gain of optical filter	1

The communication environment was chosen based on ISO (International Organization for Standardization) specification for office size which is 5m × 5m × 3m. The transmitted power per LED in a lighting source is 20mW and the array per source is 50 × 50. The receiver is placed at a table top height of 0.85m with FOV 70°. The parameters were chosen to achieve enough brightness for all considered configurations without exceeding ISO limits for illumination of an office size environment which is 300-1000 lx (Ding et al., 2012).

Figure 3 shows the received power distribution for configuration 1 to configuration 6 respectively. This was done with the half power angle at the minimum selected value of 10°. It can be seen from all the figures that the received power distribution is not uniform, most of the power is in receiver locations around the areas directly under the different transmitters. Table 2 summarizes the results and it is clear from the table that configuration 3 has the highest average received power at 2.8139mW while configuration 4 has the lowest average received power at 2.6700mW.



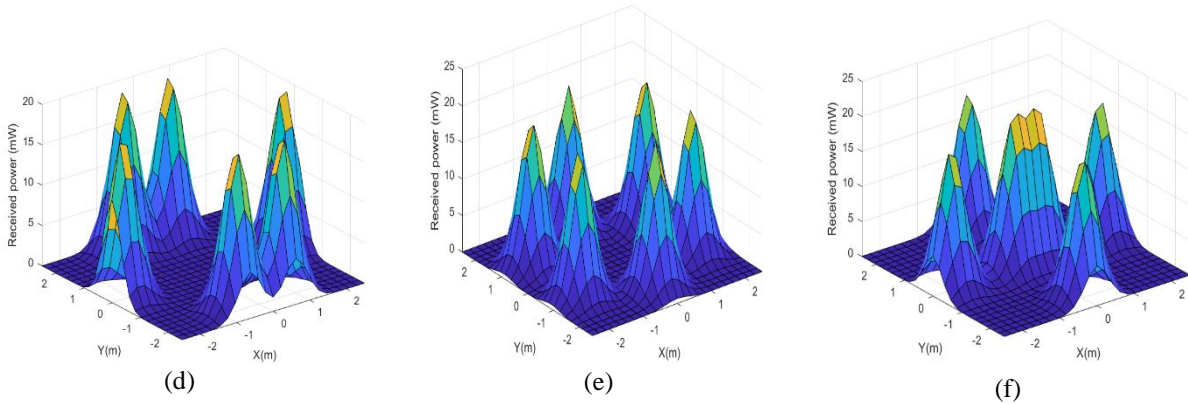


Figure 3: Received power distribution at half power angle of 10° (a) First configuration (b) second configuration (c) third configuration (d) fourth configuration (e) fifth configuration (f) sixth configuration

Table 2: Average received power P_a in mW for the six different configurations at the varying transmitter half power angles from 10° to 80°

	10°	20°	30°	40°	50°	60°	70°	80°
1 st	2.7645	2.4760	2.1695	1.8763	1.6286	1.4337	1.2813	1.1552
2 nd	2.8119	2.5619	2.1894	2.8703	1.6162	1.4204	1.2687	1.1436
3 rd	2.8139	2.6326	2.3160	1.9993	1.7308	1.5201	1.3560	1.2207
4 th	2.6700	2.2431	1.9459	1.6945	1.4826	1.3133	1.1792	1.0672
5 th	2.8120	2.5874	2.2432	1.9265	1.6668	1.4647	1.3077	1.1782
6 th	2.7636	2.4902	2.2402	1.9657	1.7152	1.5125	1.3523	1.2192

In Figure 4, simulation results for the received power in all receiver locations when the half power angle is at the maximum selected value of 80° are shown. The figures clearly depict in this case that the received power is much more uniform than the 10° half power angle. The configuration with highest average received power is configuration 3 with 1.2207mW and the one with lowest average received power is configuration 4 with 1.0672mW. It can be deduced that the uniformity improves with wider transmitter half power angle since the light is able to spread to more portions of the indoor space. Table 2 summarizes all the results of average received for several half power angles as we progressed in steps of 10° from 10° to 80° for the individual configurations.

However, it is noteworthy that each time the half power angle increases which in turn improves the distribution uniformity, the average received power tends to decrease for all transmitter configurations. Hence, there is an inverse proportion between half power angle and average received power, a direct proportion between half power angle and distribution uniformity and an inverse proportion between distribution uniformity and average received power. Table 2 clearly shows this trend for the half power angle against average received power, for all the transmitter configurations. It is also obvious from Table 2 and Figure 5 that reconfiguring the transmitter arrangement can affect these deductions.

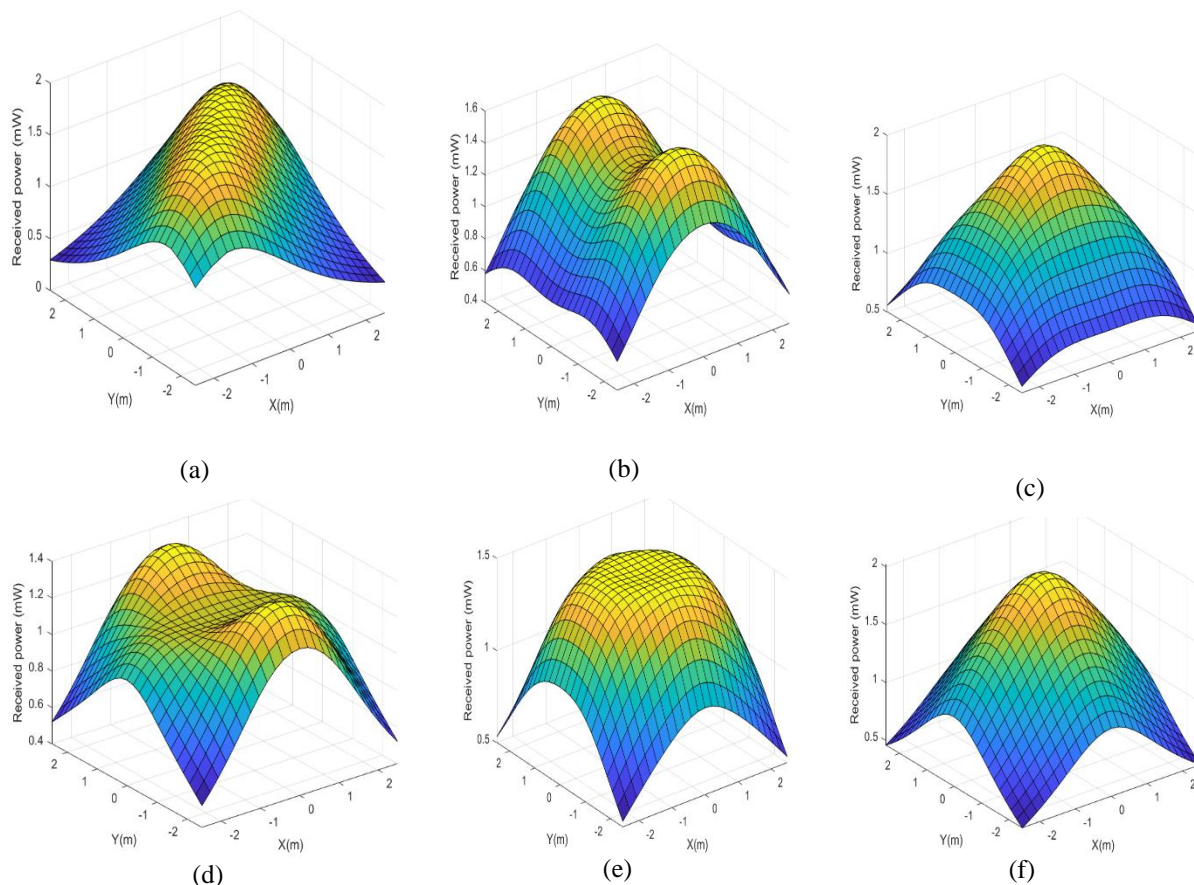


Figure 4: Received power distribution at half power angle of 80° (a) First configuration (b) second configuration (c) third configuration (d) fourth configuration (e) fifth configuration (f) sixth configuration

The image in Figure 5 shows a graphical representation of the performance of each configuration against others, in terms of average received power vs half power angle. The plot was obtained using data from simulations as tabulated in Table 2. It can be seen that the 4th configuration has the worst performance out of all the configurations with average received power at all half power angles that is less than that of the other configurations. This is also clearly observed from Table 2. The 3rd configuration has the best performance out of all configurations at all values of half power angles and should be considered for improved average power performance if it is the parameter of interest in a given VLC system of 6 transmitters.

However, for the other configurations as seen from Figure 5, some started out with a good performance with respect to others at lower half power angles like the 5th configuration but the performance dropped at higher half power angles with respect to some of the other configurations. A configuration like the 6th configuration started out poorly at lower half power angles but drastically improved to have the second best result out of all the other configuration as the half power angles began to grow. This clearly indicates the combined effect of transmitter configuration and half power angle on performance of VLC in terms average received power in a receiving plane which can aid design of VLC systems that may be based on 6 transmitters.

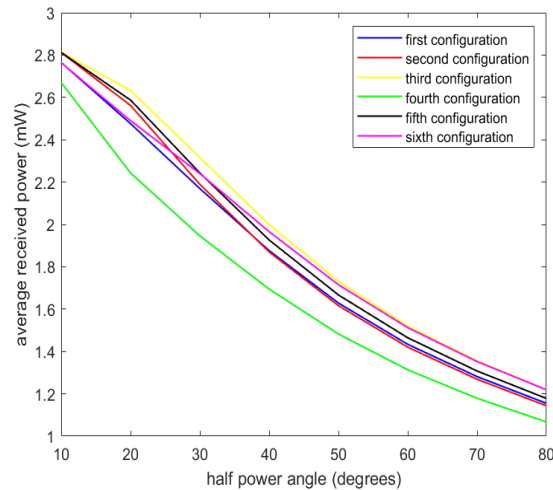


Figure 5: Average received power performance comparison between the six different configurations

The findings have clearly identified the importance of choosing the right transmitter configuration at the right transmitter half power angle in order to achieve a good power spread within the communication environment. From this work and in respect of the 6 chosen transmitter configurations for the simulations, the 3rd configuration clearly outperforms the remaining 5 configurations by having the highest average received power at both the lowest and highest half power angles which is 2.8139 mW at 10° and 1.2207 mW at 80° respectively. The 3rd configuration also performed better at all the remaining angles in between as seen from Table 2.

4. Conclusion

This work was carried out to look into how varying the transmitter half power angle alongside the chosen configuration of transmitter can affect received power at the receiver of indoor VLC system. The results obtained showed that out of the six selected configurations, the 4th configuration had the worst average received power performance while the 3rd configuration had the best average received power performance out of all the selected configurations and should therefore be adopted against the other configurations discussed in this work from the point of view of average received power. The results of this work have also generally shown that the quality of communication in VLC is affected by how the transmitters are arranged to emit the light to the receiving plane and also the angle at which they do that. Hence, this consideration should always be taken into account in designing VLC systems physical links.

In further researches, an optimal arrangement and half power angle for maintaining high average received power and distribution uniformity can be investigated. Different number of transmitters can also be considered to see the performance and the trend of different arrangements against each other in terms of various communication parameters. The non-line of sight link can also be taken into account in future researches.

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