

Analytical Study of Signal-to-Noise Ratio for Visible Light Communication by Using Single Source

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Abstract: Problem statement: In this study, optical wireless communication system using visible light is studied for indoor application. **Approach:** The process started with the calculation on performance of single source white LED where received power, channel DC gain and quality of data transmission (SNR computation) are identified. Through the simulation results, the SNR performance is directly proportional to angle of incident but inversely proportional with the distance. **Results:** The result at minimum SNR, which is 15dB, the maximum distance, is recorded at 3.0785 m while the other parameter which is angle of incident is recorded at 56.989°. **Conclusion:** A better performance is needed to improve the reliability of the system because based on the analytical modelling; it proves that this system is expected as indoor communication for next generation.

Key words: Optical wireless communication, white LED, single source, Light Emitting Diodes (LEDs), direct detection, Intensity modulation, Bit Error Rate (BER), Signal-to-Noise Ratio (SNR)

INTRODUCTION

Light Emitting Diodes (LEDs) have many advantages compared to other kind of light sources. The main point of LEDs lighting is reduced power consumption, where it emit light much faster after power is applied and it stop emitting light much sooner after power is interrupted, which is especially important in some applications. It also more advantageous compared with conventional lighting methods in terms of high efficiency, less temperature dependent, long life time, robust, small in size, lower voltage, cooler operation and so forth (Rahman *et al.*, 2011). At the same time, Visible Light Communication (VLC), is a new kind of optical wireless communication system which applied high brightness visible LEDs as transmitter to set up an optical free-space link with the receiver for high quality transmission of data. Generally, the VLC system is forming into of high brightness visible LEDs and photodetectors, which established of both transmitter and receiver, respectively (Komine and Nakagawa, 2003).

In this system, Intensity Modulation with Direct Detection (IM/DD) is employed and a directed Line-of-Sight (LOS) link has been considered. Noted that, IM/DD is often applied in applications such as short-haul optical fiber communications and diffuse indoor wireless optical links where inexpensiveness hardware is consumed (Kahn and Barry, 1997). In this kind of systems, the data is modulated on optical intensity of transmitted light using an optical intensity modulator, where the optical intensity is proportional to the transmitted electrical signal. While in the receiver, direct-detection technique is used in which the photo detector generates an output which is proportional to incident received instantaneous power. VLC can be applied in a various applications for both indoor and outdoor environment. But in this research, the proposed system setup considered an optical wireless communication system utilizing LEDs for indoor environment only, as illustrated in Fig. 1 (Kahn and Barry, 1997).

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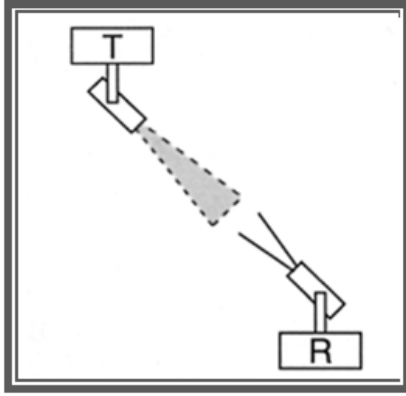


Fig. 1: Directed Link Employs Directional transmitter (LEDs) and receiver (photo detector)

In the other hand, the quality of data transmission in the VLC system can be evaluated through the Bit Error Rate (BER) and Signal-to-Noise Ratio (SNR) computation. The performance of the system is usually rely on external factors such as noise, Intersymbol Interference (ISI), distance between the transmitter and receiver, transmitted power or luminous intensity of LED lights, angle of reflection and so on. This research specifically will look into the above mentioned factors and will concentrate on SNR computation.

MATERIALS AND METHODS

The process in analyzing the effect of incident and irradiance angle on SNR ratio involves the usage of MathCAD tools. All parameters and calculations that related to this purpose is separated by Part A, B, C and D, where it represents for ‘Received Power for Single Source’, ‘Channel DC Gain’, ‘Quality of Data Transmission (SNR Computation)’ and ‘Parameters for Analysis’, respectively (Dediang *et al.*, 2007).

Received power for single source: The received power that given by channel DC gain is:

$$Pr := H(0).Pt$$

where, $H(0)$ is channel DC gain and P_t is the transmitted power. In this analysis, we set the value of transmitted power at 1 W, where the value of it is calculated based on equation below:

$$Pt = \lim_{T \rightarrow \infty} \frac{1}{2T} \int_{-T}^T X(t) dt$$

where, $X(t)$ represents instantaneous input power.

Channel DC gain: Channel DC gain is given by:

$$H(\psi, \phi) := \frac{(m+1).A.\cos(\phi)^m.Ts.g(\psi).\cos(\psi)}{2.\pi.d^2}$$

where, m is an order of Lambertian emission, A is physical area of detector in photo detector, Φ is the angle of irradiance, T_s is a gain of optical filter, $g(\psi)$ is the gain of optical concentrator, ψ is the angle of incidence and d is the distance between transmitter and receiver.

In order to get Lambertian emission, equation below is used:

$$p := \frac{-\ln(2)}{\ln(\cos(\phi_c))}$$

where, ϕ_c is transmitter semiangle which defined at half power.

While the optical concentrator $g(\psi)$ equation is then given by:

$$g(\psi) := \begin{cases} \frac{(n^2)}{(\sin(\psi_c))^2} & \text{if } 0 < \psi < \psi_c \\ 0 & \text{otherwise} \end{cases}$$

where, n represents the refractive index and we set the value at 1.5.

Quality of data transmission (SNR computation): In the wireless communication, the bandwidth will likely be much higher than data rate, so that the system can operate at very low SNR (Ganapathy and Sagayaraj, 2010).

The SNR is given by:

$$SNR = \frac{\gamma^2 Pr^2}{\sigma_{total}^2}$$

where, γ is the photodiode responsibility (A/W) and σ_{total}^2 is total noise variance and it is given by this equation:

$$\sigma_{total} = \sigma_{thermal} + \sigma_{shot}$$

In order to get total noise variance, the thermal noise variance equation is given by:

$$\sigma_{thermal} := \left(\frac{8\pi.k.Tk.\eta.A.12B^2}{G} \right) + \left(\frac{16\pi^2.k.Tk.T.A^2.13B^2}{gm} \right)$$

Table 1: Parameters for simulation

Receiver area, A	$5 \times 10^{-4} \text{ m}^2$
Filter gain, T_s	1
Angle of irradiance, ϕ	15°
Distance, d	0.85 m
Angle of incidence, θ	60°
Transmitter semi angle, ϕ_c	60°
Photodiode responsibility, γ	0.54 A/W
ψ_c	60°
Boltzmann's constant, k	$1.3806488 \times 10^{-23} \text{ J/K}$
Absolute temperature, T_k	300 K
Fixed capacitance of photo detector per unit area, η	1.12 u m^{-2}
Noise bandwidth factor, I_2	0.562
I_3	0.0868
Noise bandwidth, B	100 MHz
Open-loop voltage gain, G	10
FET channel noise factor, Γ	1.5
FET transconductance, g_m	30 ms
Electronic charge, q	$1.6 \times 10^{-19} \text{ C}$
Background current, I_{bg}	$5100 \times 10^{-6} \text{ A}$
y	2 m

Where:

- k = Boltzmann's constant
- Tk = Absolute temperature
- η = Fixed capacitance of photo detector per unit area
- I_2 = Noise bandwidth factor
- B = Equivalent noise bandwidth
- G = Open-loop voltage gain
- Γ = FET annel noise factor
- g_m = FET transconductance

In the other hand, shot noise variance is given by:

$$\sigma_{\text{shot}} := 2q \cdot I_{bg} \cdot 12B + Pt \cdot 2 \cdot q \cdot \gamma \cdot B \cdot (H(\psi))$$

where, q is the electronic charge and I_{bg} is background current.

Parameters for analysis (calculation and simulation): All values that we used in order to get all the calculations above (in part A, B and C) are listed in Table 1 below.

RESULTS

Figure 2 shows the simulated SNR and angle of incident versus distance characteristic of receiver to determine the signal quality by using single source of light. By looking at Fig. 2, we can see at minimum SNR, which is 15dB, the maximum distance, is recorded at 3.0785 m. The other parameter, which is angle of incident, is recorded at 56.989° . Theoretically in wireless communication, the acceptable value of SNR is 15dB and because of this reason, we set the SNR at this point to analyze the value for angle of incident and distance (Zeng *et al.*, 2008). Noted that, SNR is proportional to angle of incident but it is inversely proportional to the distance.

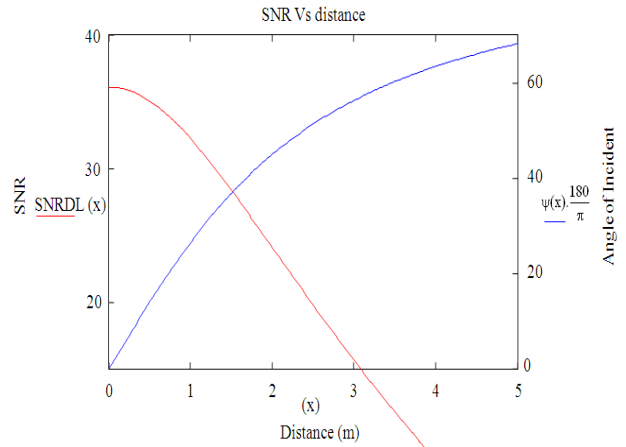


Fig. 2: SNR and angle of incident vs distance

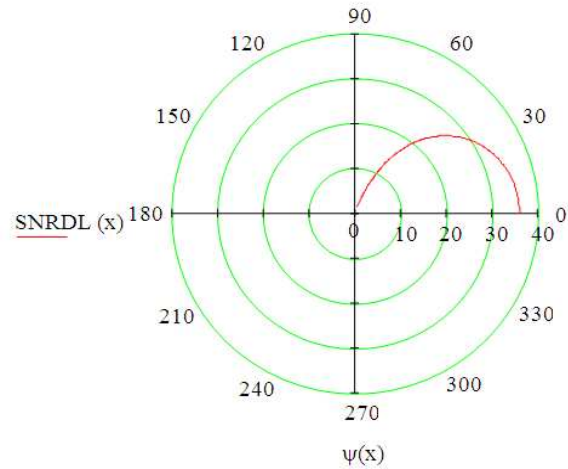


Fig. 3: Polar graph of SNR and angle of incident

A better explanation is shown at Fig. 3 where polar graph is presented. It is also synchronize with result that we get at Fig. 2 which the SNR is 15dB, thus the angle of incident will be at 56.989° .

DISCUSSION

For a line of sight configuration, the incident power collected by the photodiode at the receiver end depends on the transmitted power, on the geometry of LED to photodiode, on the channel attenuation and on the receiver model (Komine and Nakagawa, 2004). A simple model for optical communication can be considered as in Fig. 4, where it explained and synchronizes with the result that we get from the graph Fig. 2 on why SNR is directly proportional to angle of incident but inversely proportional with the distance.

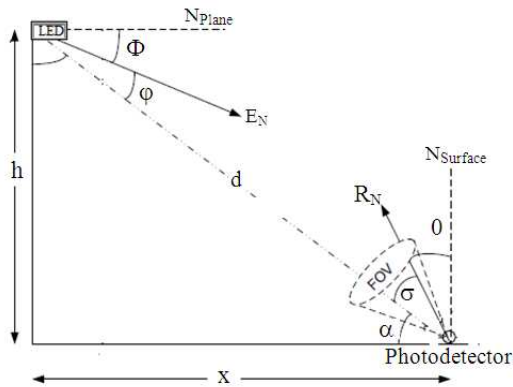


Fig. 4: A simple model for optical communication

From Fig. 4, obviously it has shown a relation between Field Of View (FOV) and received SNR with intersymbol interference. The communication performance is degraded severely by inter symbol interference. In visible light communication system, the LED lights are distributed within a room and the irradiance of light is wide for function of lighting equipment. Therefore, the intersymbol interference is depended on the data rate and FOV of receiver. Noted that when FOV is smaller than 40° , the blind area will exist (Tanaka *et al.*, 2003). The received SNR is required throughout a whole box/room when FOV is $40-60^\circ$. Small angle of irradiance gets better performance since the intersymbol interference is decreased.

CONCLUSION

In this study, in order to observe the incident and irradiance effect on the SNR performance, the two-dimensional of transmitter and receiver of VLC application with varying distance has been simulated using the MathCAD tools. Through the simulations, the SNR performance is directly proportional to angle of incident but inversely proportional with the distance. In general, a higher SNR has a better performance due to the larger number of incident angle that available. However, the distance for a better performance must also be decreasing. Thus, to optimise the performance of a system, the angle of incident needs to be customised to suit its application. From the analytical study, a single source of visible light using LED is able to be used for communication and because of this reason, further process and study is continuing for real implementation is achieved.

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