Light detection experiment with avalanche photo diode and pin photo diode for green visible light communication

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Abstract. Visible Light Communication (VLC) has been attracting many researchers in the last decade to develop a lighting system as well as a communication system simultaneously. Light Emitting Diode (LED) for lighting systems are becoming more popular and widespread. It offers low consumption energy due to its energy transfer efficiency from electric to light. LED also offers a high response for modulation that makes it is also possible for communication purposes. Therefore, an improved configuration can provide a green communication system by reducing power consumption through combining lighting and communication system. Detection responsivity is a challenging issue to realize a VLC system. It will affect covered areas and obtained signal quality. This paper discusses the use of PIN photodiode and Avalanche Photo Diode (APD) for a detection device in a digital transmission data. This detector is generally used for fiber optic systems and offers an avalanche effect that can increase the obtained photocurrent. The obtained proper configuration and multiplication effect characteristics will be useful for designing a VLC system for green communication.

1. Introduction
Green ICT is currently becoming a hot issue in the information and communication technology (ICT) business. The concept of Green ICT is to reduce energy consumption and other natural resources as well as reduce carbon emissions and waste generated from ICT activities. The global ICT industry contributes around 2% of carbon emissions to total world carbon emissions [1]. The carbon emissions come from the use of ICT devices such as personal computers (PC), servers, wired and wireless telephone systems, and others. The ICT eco-friendly has activities and behaviors conducted in manufacturing, shipping, installation, use of recycled ICT products, development and provision of ICT services, use of environmentally friendly materials, reduction in paper use and reduction of energy consumption [2].

In Indonesia, there were 55 million internet users at the end of 2011 and grew to 62 million in October 2012 [1][3]. Also, there were 78,160 2G Base Transceiver Station (BTS) spread throughout Indonesia [4]. From these data, the use of ICT is very high and will continue to grow so that it will have an impact on increasing carbon emission from the ICT sector. Besides, more exploration of more complex and evolving techniques in communication technology using radio frequencies has led to higher power consumption to maintain its connection [5] [6] [7]. Therefore, there is a demand for other alternative technologies to reduce power consumption, which can also contribute to carbon emission due to power production.

For indoor communication using wireless technology, visible light communication (VLC) offers some advantages, such as green technologies and cost-effective [8]. VLC technology works by using the light spectrum, which has wavelengths from 375 to 780 nm. The range wavelength in the VLC
system offers free licenses and free electromagnetic interference from other communication systems. Apart from communication, another advantage of the VLC system is for lighting at the same time as communicating. These advantages support Green ICT, which combines two systems that work together and simultaneously reduce the power needed compared when each system works separately. Compared to other communication such as radio-frequency (RF) and infra-red technologies, VLC also offers another advantage, which is cheaper than the two due to the availability of light-emitting diode (LED) components that already widely for lighting systems [9]. Besides LED, the laser also can be used as another optical source. Still, LED can cover a larger area than other optical sources that are often used in wired optical communication [10].

The wavelength spectrum that this system has is very short compared to the radio and infrared spectrum, which causes limitations in mobility and coverage area. This system also suffers high free space losses, and it isn't easy to pass through materials like walls. That is why this system is a solution for indoor communication. Another disadvantage of the VLC system is high interference from other light sources. In a bright room, it may not be illuminated by one light source, but by another light source. This condition can cause noise in the propagation channel and reduce the quality of the received signals. Therefore, developing an effective and efficient VLC system requires a good understanding of the characteristics of the VLC system and the propagation of visible light in free space and the right configuration.

This paper discusses an experiment of digital data transmission using LED as an optical source and two types of the photodiode, which is Avalanche and PIN photodiode as an optical detector to investigate propagation effects on this experiment. The purpose is to compare performance between Avalanche and PIN photodiode as an optical detector.

2. Experiment Schematic And Setup
Figures 1 and 2 show an illustration of simplex data communication flow and schematic to measure voltage and current at the receiver side. The main components for this experiment are personal computer and microcontroller for reading digital data, LED and photodiodes as a transducer for this wireless communication. The considered microcontroller is Arduino Mega 2560, which works at an operating voltage of 5V. It has 54 pins for digital input/output and 16 pins for analog input. The DC currents consist of 20 mA for I/O pin and 50 mA+ for 3.3V pin. The clock speed of this microcontroller is 16 MHz. The considered optical source is Keyes 10 mm RGB LED Module with diameter 10 mm and consists of red, green, and blue colors. The LED minimum and maximum operating temperatures are -40°C and 85°C and have four pins for voltage input, red, green, and blue. Table 1 shows the differences between two types of photodiodes for the experiment, which are PIN and Avalanche photodiodes.

![Figure 1. An illustration of simplex data communication flow](image-url)
Figure 2. A schematic of voltage and current measurement at the receiver.

Table 1. Differences between PIN and Avalanche photodiode.

| Specifications                        | PIN      | Avalanche |
|---------------------------------------|----------|-----------|
| Model                                 | PIN SFH 203 P | APD AD500-8 |
| Peak wavelength (nm)                  | 850      | 800       |
| Responsivity (A/W)                    | 0.62     | 50        |
| NEP (W/√Hz)                           | 2.9 x 10^{-14} | 2 x 10^{-14} |
| Detection Limit (cm x √Hz^2/W)        | 3.5 x 10^{12} | 9.8 x 10^{11} |
| Active area (mm^2)                    | 1        | 0.196     |

At the receiver side, the photodiode connected to an analog input pin, and the circuit is connected to two resistors of each 10 kΩ in series to prevent unexpected short circuit conditions. A voltmeter and ammeter that are connected in parallel and series with a photodiode measure voltage different and photocurrent. This research considers variables variation of distance and optical wavelength to investigate voltage and current. For the variation of wavelengths, this experiment uses the color of red, green, and blue from the LEDs to transmit optical signals.

3. Results and Discussion

A. Voltage and Current Detection

Figures 3 and 4 show the experiment results of voltage and current detection by PIN photodiode and by APD, respectively. For PIN photodiode, the varying distances between transmitter and receiver to measure voltage and current is from 1.5 cm to 3.6. Meanwhile, for APD, the varying distances are in a range from 1.5 cm to 3.2 cm because when measuring the voltage and current at 3.4 cm, there is already no change. So, the limit distance for APD to receive photons from the RGB LED is 3.2 cm. Figures 3 (a) and 4 (a) show that the farther the distance between LED and sensor, the smaller the value of voltage detected by PIN and APD, respectively. Figures 3 (b) and 4 (b) show that the farther the distance between LED and sensor, the smaller the value of current detected by PIN and APD, respectively. This condition is affected by following the general path loss theory, where the intensity of LED decreasing as the distance becomes further. The experiment by using a white LED produces the highest detected value of voltage and current. White LED can detect voltage and electric current better than other colors because by using RGB LED, white light coming from mixing red, green, and blue light. Therefore, the white LED power is also an accumulation from red, green, and blue.
By considering Equation 1, the higher the wavelength of the light spectrum, the smaller the photon energy. Between red, green, and blue light, blue light has the highest photon energy than green and red because its wavelength is smallest than green and red. Therefore, the blue LED has the highest intensity than other colors, so the photodiode produces better voltage and current. The smallest voltage and current produced by the red LED because its photon energy is smallest, among other colors.

\[ E = hf = \frac{hc}{\lambda} \]  

(a)     (b)

Figure 3. Experiment results of (a) voltage and (b) current detection by varying LED colors measured at the receiver by PIN.

(a)   (b)

Figure 4. Experiment results of (a) voltage and (b) current detection by varying LED colors measured at the receiver by APD.

B. Received Power

The received power \( (P) \) by the sensors can be calculated by Equation 2 using parameter current \( (I) \) and voltage \( (V) \) from the measurement. Figure 5 shows received power by both of the sensors as a function of distances calculated from the measured voltage and current at the receiver. The different wavelengths produce by RGB LED affect the different conversion efficiency at the PIN and APD, from photon energy to electric energy and losses along with transmission. The higher the responsivity of the sensor, the smaller the photon energy needed to the sensor to detect the light. The Parameter for calculating the minimum amount of photon energy so that the sensor can produce electricity called Noise Equivalent Power (NEP) [11]. From the sensor specification, APD has the smallest NEP than a PIN, which means APD is more sensitive to the light than a PIN. Even though the APD can detect better than the PIN, so
the received power by APD should be higher than a PIN, the experiment results from figure 4 show the opposite. This condition occurs due to the active area of the sensor. The active area of APD is only about 10% of the PIN active area, which means the APD can absorb 10% of the photons of the PIN and PIN can convert the light into electrical power around ten times better than APD. From 1.5 cm to 2 cm, the red LED suffers the smallest losses of around 0.0194 mW, and the blue LED has the highest losses of around 0.0335 mW at the same distance, which is related to Equation 3. More distance will provide more losses, and the higher the wavelength, the smaller losses in the air. That shows that the red LED suffer fewer losses than other colors. Therefore, Figure 5 shows the gradient of the red LED is the smallest among the others.

\[ P = V \times I \]  
\[ P_L = \left( \frac{4\pi R}{A} \right)^2 \]  

**Figure 5.** Received power as a function of distances calculated from the measured voltage and current at the receiver by (a) PIN and (b) APD

4. **Conclusion**

This paper has observed the differences received power using two different kinds of photodiodes. The received power by PIN is ten times better than APD because of the active area of PIN is bigger than APD. The white LED shows the highest received power than red, green, and blue. The received power of the white LED is 0.2535 mW and 0.0154 mW at the distance of 1.5 cm by PIN and APD, respectively. The red LED shows the smallest received power among the others, the received power at the distance of 1.5 cm is 0.0266 mW for PIN and 0.0015 mW for APD. This condition offers the advantage of using a white LED as a source for a VLC system and lightning at the same time to deploy green communication.

5. **References**

[1] K. K. D. I. R. INDONESIA, KOMUNIKASI DAN INFORMATIKA INDONESIA BUKU PUTIH 2012, JAKARTA: Badan Penelitian dan Pengembangan Sumber Daya Manusia Kementerian Komunikasi dan Informatika, 2012.
[2] P. Fernando and A. Okuda, "Green ICT: A “Cool” Factor in the Wake of," 2009.
[3] APJII, "Pengguna Internet 2012," 2012.
[4] D. P. PPI, "Statistik ADO," Kominfo, 2011.
[5] M. Yan, C. A. Chan, A. F. Gygax and J. Yan, "Modeling the Total Energy Consumption of Mobile Network Services and Applications," *Energies*, vol. 12, p. 184, 2019.

[6] H. Pihkolah, M. Hongisto and O. L. M. Apilo, "Evaluating the Energy Consumption of Mobile Data Transfer—From Technology Development to Consumer Behaviour and Life Cycle Thinking," *Sustainability*, vol. 10, p. 2494, 2018.

[7] L. Decreusefond, T. Vu and P. Martins, "Modeling energy consumption in cellular networks," in *Proceedings of the 2013 25th International Teletraffic Congress (ITC)*, Shanghai, 2013.

[8] D. Tsonev, S. Videv and H. Haas, "Light fidelity (Li-Fi): towards all-optical networking," in *SPIE OPTO*, San Francisco, California, United States, 2014.

[9] D. Karunatlaka, F. Zafar, V. Kalavally and R. Parthiban, "LED Based Indoor Visible Light Communications: State of the Art," *IEEE Communications Surveys & Tutorials*, vol. 17, no. 3, pp. 1649 - 1678, 2015.

[10] Yudiansyah, P. D. Mariyam, A. P. Aji, N. Chisnariandini and C. Apriono, "Design of land optical fiber backbone communication network in North Sumatera," in *2018 International Conference on Information and Communications Technology (ICOIACT)*, Yogyakarta, 2018.

[11] T. K. a. G. M. Rebeiz, "A Low-Power 136-GHz SiGe Total Power Radiometer With NETD of 0.25 K," in *IEEE Transactions on Microwave Theory and Techniques*, vol. 64, no. 3, pp. 906-914, March 2016.

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