HIGH DATA RATE OPTICAL WIRELESS COMMUNICATION SYSTEM USING MILLIMETER WAVE AND OPTICAL PHASE MODULATION

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ABSTRACT

An optical-wireless communication (OWC) model with the generation 60 GHz millimetre wave (mm-wave) is discussed and investigated. This system is proposed to transfer a digital signal with a 320 Mbps data rate by using an optical signal over a wireless channel as a part of visible light communication (VLC) in the fifth generation (5G) for small cell networks. The electrical generation domain has a challenging with the mm-wave; therefore, our model is introduced and examined. The mm-wave and phase modulation are proposed in the optical wireless communication for the first time. OWC system with 320 Mbps signal transmission is successfully achieved. In our simulation, the directly modulated laser (DML) is driven by the digital signal; then, the generated optical signal is mixed by the phase modulator with 60 GHz mm-wave carrier to result in a phase modulated optical signal to be transmitted over the wireless channel. Based on the simulation results, the proposed OWC system is successfully working to transfer a 320 Mbps data rate over 10m wireless channel distance with low BER (10^{-5}) and good Q-Factor (4). The simulation results show that a cost-effective operation with mm-wave for faster transmission. This research ensures a possible optical link with low cost and RF interference.

Keywords: 60 GHz frequency band, millimeterwave (mm-wave), optical-wireless channel, optical-wireless communication (OWC), visible light communication (VLC), Q-Factor; eye diagram, BER; optisystem, 1550 nm wavelength.

1. INTRODUCTION

The improvement and the implementation of the millimeter wave spectrum for 5G communication networks have encouraged due to the overcrowded microwave band and the lack of global bandwidth for wireless communications. The available radio spectrum becomes insufficient below 10 GHz (cm-wave communication). In responding to this challenge, the wireless communication industry takes into consideration the radio spectrum above 10 GHz (mm-wave communication) [1].

The optical spectrum can be served as a reliable spectrum resource for wideband wireless communications. The benefits of optical wireless communications (OWC) primarily lie in two aspects: due to the high carrier frequency, the transmission bandwidth will be potentially significant, and because of there is no radio frequency radiation, the security of communication requirements will be a simple issue. Thus, OWC can apply in the scenarios where the radio silence is essential, or the radiation of radio frequency may cause explosions [2]. OWC is propagating signals through at a wavelength between 380nm to 740nm for VLC and 750nm to 1600nm for laser through open and freespaces. OWC is considered as a promising solution for the "last mile" bottleneck in wireless communications because it requires no licenses of the spectrum, and consequently saving acquiring cost [3], [4]. Comparing with radio frequency (RF), it is facing a soon to be a full spectrum, evolving terrorism and security issues, the excessive cost of installation and low data rate.
As for optic fiber technology, although it provides good QoS however, it unable to reach everyone specifically in the countryside areas and since it is a wired technology, the mobility advantage is not available [5]. The applications of the OWC system are varying from short range to ultra-long range. Presently, space and military operations are used OWC systems. Vendors have begun providing OWC system to commercial and industrial players as well. It anticipates that by 2020, RF technologies power consumption will be controlled by the global network. However, the best data rate and the lowest normalized energy consumption are provided byoptical link compared to the rest of RF wireless communication standards [6].

Significant advantages have offered by the OWC system to the communication landscape. However, several challenges it poses. According to Debbie Kedar and Shlomi Arnon [7], they have recognized that OWC system affected by problems such as the LOS alignment with the transmitter and the receiver module because of external weather conditions like wind sway or weak earthquakes.
Also, Ahmed Nabih [8] stated that weather conditions such as fog rain, snow, or even clouds might absorb the light wave propagation and small water particles from the storm can also cause particles scattering. These conditions will cause that the performance of the OWC system to be affected like particle scattering will result in signal attenuation and distortions.

Nakagawa *et al.* [4] improved a data transmission system utilizing white LEDs that can be used in the indoor environment.

A novel scheme for short-range optical wireless audio signal communication utilizing white LED lighting system is described in [9]. In [10] the researcher explains the optical wireless communication system by building a simulated and an experimental model using a laser diode as the propagation medium.

In this research, we are going to build a new simulation model of OWC differs from the former studies by considering the performance of the mm-wave and

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phase modulation. Using a single laser source with 1550 nm wavelength is a cost-effective solution regarding the complexity and processing. The proposed system of OWC has not applied an expensive component such as an optical or electrical amplifier and optical filter to prove that the simulation can give a better at the output of photodetector. The organization of this paper is as follows: Section 2 debates the principle and architecture of the proposed system of OWC. Section 3 presents the system configuration. The optical wireless channel model is investigated in section 4. The simulation results and discussion are shown in section 5. Finally, section 6 summarizes the main point of the paper.

2. SYSTEM PRINCIPLE AND ARCHITECTURE

In this section, the operating principle of the proposed a 60 GHz mm-wave/ 320 Mbps Signal transmission based on 1550 nm over OWC is presented, and the evaluation of the system performance is discussed. Figure-1 explains the schematic block diagram of the proposed system design. The system consists of two central part: transmission and reception parts. The transmission part includes of a directly modulated laser (DML), which is operated by data signals, a phase modulator, which is operated by RF/mm-wave signals of the local oscillator.

In our system, we use a phase modulator because it has many benefits as follows: it can work without the need to an electrical circuit to the D.C base control; it has a small insertion loss. This leads to making the communication system has more significant margin. As aforementioned, the phase modulator is driven by an RF/ mm-wave signal, in turn, points to achieve a small modulation depth. As a result, the cost-effective operation can achieve by reusing the rest of the optical carriers. Furthermore, the noise bins signals have not been affected by the phase modulator. From the technical perspective, the phase modulator uses the concept as a Mach-Zehnder modulator (MZM), but it has one arm. It has a switching voltage (V_π) and feed via laser power (P_{in}), thus, the output optical field of the phase modulator can be calculated by Equation (1).

$$E_p(t) = e^{j\frac{\pi V(t)}{2V_\pi}}\sqrt{2P_{in}e^{jw_c t}} \quad (1)$$

where w_c is the mm-wave frequency, and $V(t)$ denotes the electronic modulating signal. The electrical modulating signal is modulated on an optical carrier by a phase modulator. So, the output optical signal describes via Eq. (2).

$$E_{out} = E_{in}(t).e^{j.\Delta\emptyset.modulation(t)} \quad (2)$$

where, E_{in} (t) is the input optical signal, $\Delta\emptyset$ is the phase deviation and *modulation* (t) represents the electrical input signal [3].

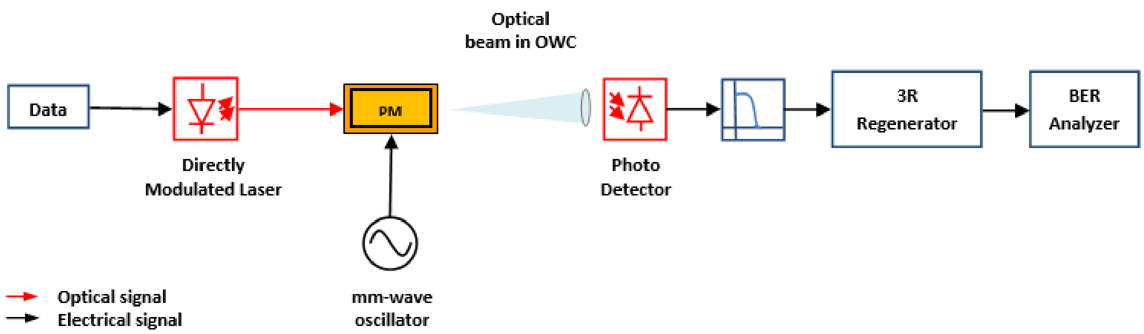

Figure-1. A schematic diagram of our proposed system for OWC.

The generated optical signals from the phase modulator are then launched into the optical wireless channel. After transmission of the signal carrier, the photodetector at the receiver will receive laser signals from the transmitter and then filtered by low pass Bessel filter to reject undesired signals. As the received signals produce voltages, then it will be converted back to the initially transmitted data by using bit sequence regenerator. It is easy to calculate the BER to the received signal via BER analyzer component to examine the quality of our system [11]. In our system, there is no requirement to use expensive elements such as an optical filter, optical amplifier, and electrical amplifier. Also, the using of the direct modulator can reduce the complexity and cost of the optical communication system. Therefore, our proposed scheme can reduce the installation cost and RF interference for faster data transmission.

3. SIMULATION SET UP

The proposed OWC system using non-return to zero (NRZ)-DML with mm-wave-phase modulation is simulated via Optisystem-14.1_evaluation software. The Optisystem is an excellent platform to simulate the optical wireless communication system to analyze the performance with minimum effort, cost and time. Our scheme that is shown in Fig. 2has the following configurations. The pseudo random binary sequence (PRBS) signal with 320 Mbps data rate enters the NRZ to generate the digital form of the data signal, which is fed the directly modulated laser with 1550 nm wavelength and 10 dBm power level. The phase modulator with 90-degree

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phase deviation ($\Delta\emptyset$) is driven by an mm-wave sinusoidal signal with a 60 GHz frequency carrier and a 0-degree phase. The OWC channel with 1550 nm wavelength and 10 m distance range, and the transmitter and receiver aperture diameters are 0.2 cm and 0.8 cm, respectively. The optical signal falls on the lens of the photodetector surface to produce the electrical signal, where PIN photodiode is chosen as photodetector due to low voltage operation, low cost, linear response properties over wide ranges and tolerance to huge temperature fluctuations [11].

The PIN photodiode configures with 0.223 A/W responsivity and 10 nA dark current. The detected signal has a noise to be added by the channel. The desired signal must extract from the detected signal via an electric allow pass Bessel filter with cut-off frequency = 0.01 * Symbol rate (Hz).The 3R generator regenerator works as a demodulator, and BER analyzer component are applied on the demodulated signal to find the BER, Q-Factor and eye diagram. Figure-2 depicts the block diagram of the proposed OWC system design.

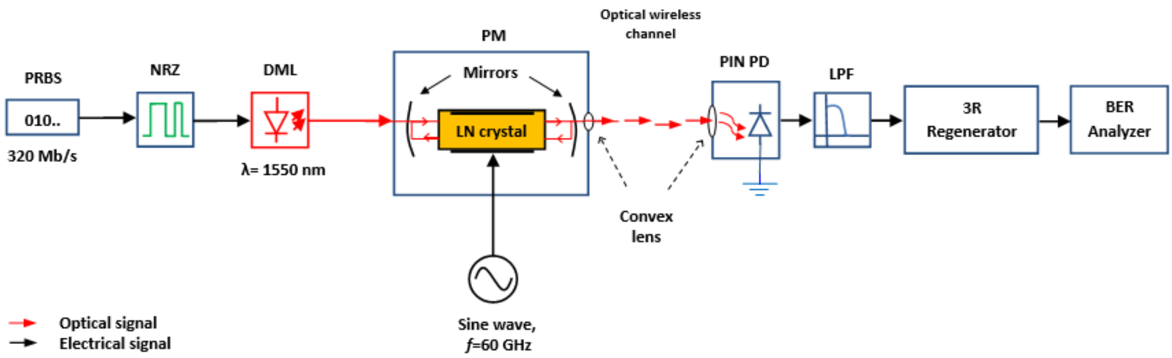

Figure-2. A block diagram of proposed OWC system using NRZ-Phase modulation.

It is clearly seen that the phase modulated optical signal is lunched from the transmitter aperture of the optical phase modulator to travel through the air, so, the signal is susceptible to the noise, interference and attenuation as a discussed in next section.

4. PROPERTIES OF OWC LINK

The input signal in free-space optical communication is typically transmitted using laser diodes or light-emitting diodes. The mode of "intensity modulation with direct detection (IM/DD)" is often applied where the inexpensive requirement is used of optical links and short-haul optical fiber communications [12], [13], [14]. In such modes, an optical intensity modulator is modulated by the data on the optical intensity of the transmitted light such as a light-emitting diode or laser diode. The transmitted signal is proportional to optical intensity. Consequently, the transmitted signal must be nonnegative [15]. At the receiver side, the receiver firstly measures the occurrence optical intensity of the received light via a front-end photodetector and generates an output signal which considered as a proportional relation to the detected intensity. The receiver decodes the transmitted data based on this output signal [12], [16], [17] [14]. The light from the optical transmitter is received by the receiver through the LOS (line of sight) channel model, which can achieve low dispersion, path loss, ISI (inter-symbol interference) and better data rate. The received optical power from the optical transmitter can be given by:

$$p_{rec} = p_i * h(0) \tag{3}$$

where, p_i denotes the transmitted optical power and $h(0)$ presents the LOS DC channel gain, which can be calculated via Equation (4):

$$H(0)_{ij} = \begin{cases} \frac{(m+1)A}{2\pi d^2}\cos^m(\emptyset_{ij})\cos(\varphi_{ij}), & 0 \le \varphi \le \varphi_c \\ 0, & 0 \ge \varphi_c \end{cases} \tag{4}$$

where, A is the surface area of the photo detector, d is the distance between the transmitter and receiver, $\emptyset_{ij}$ and φ_{ij} are the irradiance and incidence angles, φ_c is the field of view (FOV) (semiangle) at the receiver and $m = -\frac{ln2}{\ln(cos\varphi_{1/2})}$indicates the Lambertian radiant order that is related to the transmitter semiangle$\varphi_{1/2}$, (at the half power).The received power gives by:

$$P_{R\_ij} = P_{Tx}H(0)_{ij} \tag{5}$$

$$I_{ij} = \frac{P_{R\_ij}}{A_{cov}} \tag{6}$$

$$P_{Rx} = \int I_{ij}dA_{cov} \tag{7}$$

where, P_{Tx} indicates the transmitted optical power of PM and P_{Rx} denotes the received optical power. Equation (5) and Equation (6) can be substituted into in Equation (7), we will get the following:

$$P_{Rx} = \int P_{Tx}H(0)_{ij}d \tag{8}$$

The noise model must also be involved with the LOS channel model. Optical noise sources which are contributed to the OWC system contains ambient light noise, signal and ambient light created by shot noise in the photodiode and thermal noise created by the trans-impedance amplifier (TIA) [11], [18], [19].Consequently, the OWC channel is exhibited as a linear optical additive white Gaussian noise (AWGN) channel and the output photocurrent of the photo detector is given by Eq. (9)

$$I(t) = R\, p_i(t) \otimes h(t) + n(t) \qquad (9)$$

where, R is the photodiode sensitivity (A/W), $p_i(t)$ is the instantaneous input power,$\otimes$indicates the convolution process,$h(t)$ denotes the impulse response and $n(t)$ presents the shot noise and thermal noise [11], [14], [19].In our system, the direct modulated laser with a 1550 nm wavelength is used as a source of optical signal, then, the optical source is mixed with a 60 GHz mm-wave using phase modulator. The resultant signal is phase modulated optical signal, which is like an optical beam. According to Joshua et al. [10], the misalignment may be degraded the system performance. The background noises are unmodulated such as sunlight and ambient light. The artificial light noise can contribute a few micro-amperes current at the receiver. The high frequency noise signal can be removed by using an electrical low pass filter, as presented in the upcoming section.

5. SIMULATION RESULTS AND DISCUSSION

The system prototype is successfully built by using Optisystem simulation, and various tests have been done to gain the data for analyzing and calculating the results. The research investigates OWC link based on mm-wave generation and phase modulator, which is used for the first time. The obtained results of the optical and RF spectrum analyzer are schematically shown in Figure-3. The line width of optical source can be increased by exploiting direct modulated laser that is electrically driven by binary data. The continuous wave laser at the output of the direct modulated laser is represented in Figure-3 with a 1.55 µm wavelength and 10 dBm power. The optical signal enters the optical phase modulator with 60 GHz mm-sine wave signal. The phase modulator is not affected by the noise signals. The optical spectrum analyzer result from the simulation is depicted in Figure-3 for the phase modulated optical signal at the output of the phase modulator. The simulation result has a little noise on the signal with good peak power. The generated signal has sidebands, the first order sideband (FOSB) is f_m distanced from the f_c. The optical spectrum analyzer results after propagating by the optical wireless channel and before the photodetector is shown in Figure-3. The simulation result points out that the received phase modulated optical signal has low noise and received optical power, which approximately equals 8 dBm. The optical wireless communication has a 2 dBm of channel pathloss to transmit the phase modulated optical signal through a 10 m distance. Then, the signal is detected by PIN PD. We have noticed that the received electrical signal has main lobe and sidelobes. The information signal is represented as a low frequency signal; It is necessary to cut the main lobe from undesired high frequency sidelobe components via an electrical low pass Bessel filter. The filtered received data signal is demodulated by using 3R regenerator in order to test the system quality.

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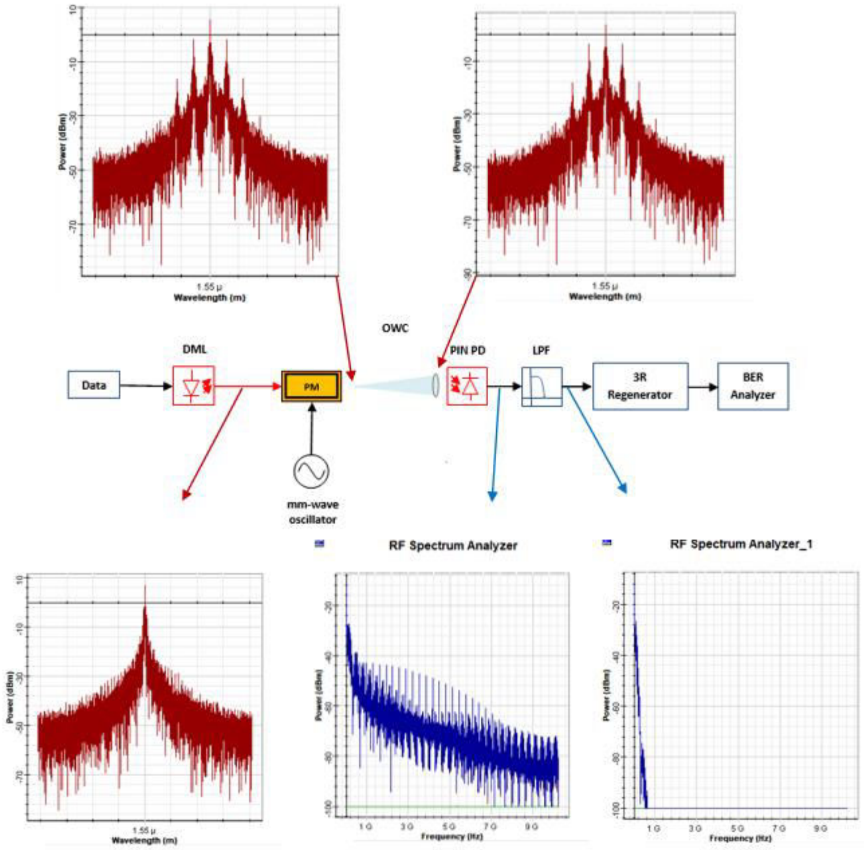

Figure-3. The experimental results of optical phase mm-wave generation method on the proposed OWC system.

The BER performance of the proposed OWC system is collected and illustrated in Figure-4. From the graph, higher BER designates that the information signal takes a higher error probability in its propagation. However, in our system, the BER is still within the range as it was initially anticipated to exponentially increasing, but it displays that it instead increased steadily. This is because of the property of laser diode at 1 nm optical bandwidth, which is less disposed to particle scattering and fading signals. Figure-5 shows the eye diagram performance of OWC system, which indicates an excellent performance and the eye is clearly opened after data transmission through 10 m. In order to measure the link performance, it has to calculate both the BER and Q-Factor for 320 Mbps data rate and 10 m transmission. We have a good BER level and Q-Factor, which is approximately equal to (10^{-5}) and (4), respectively.

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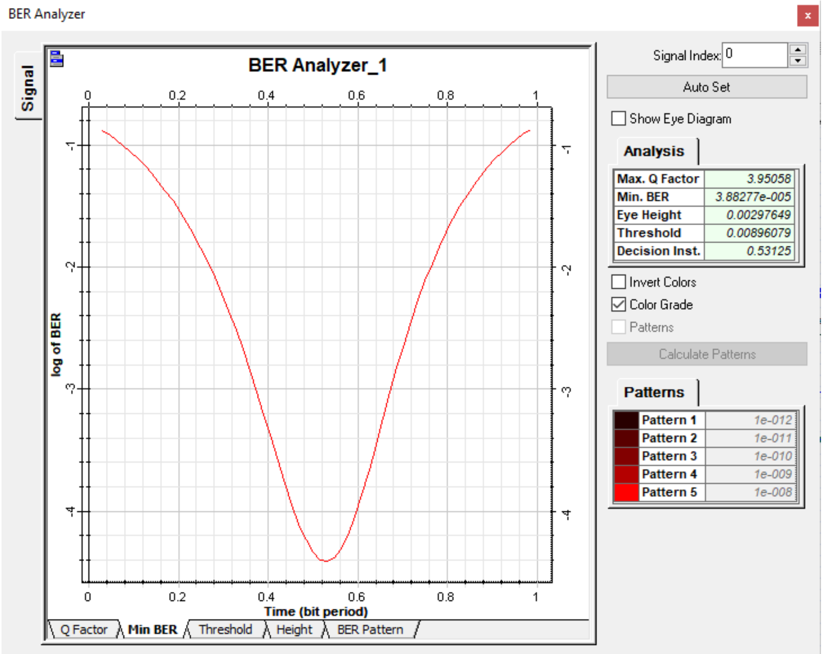

Figure-4. The BER performance of proposed OWC system at 10 m.

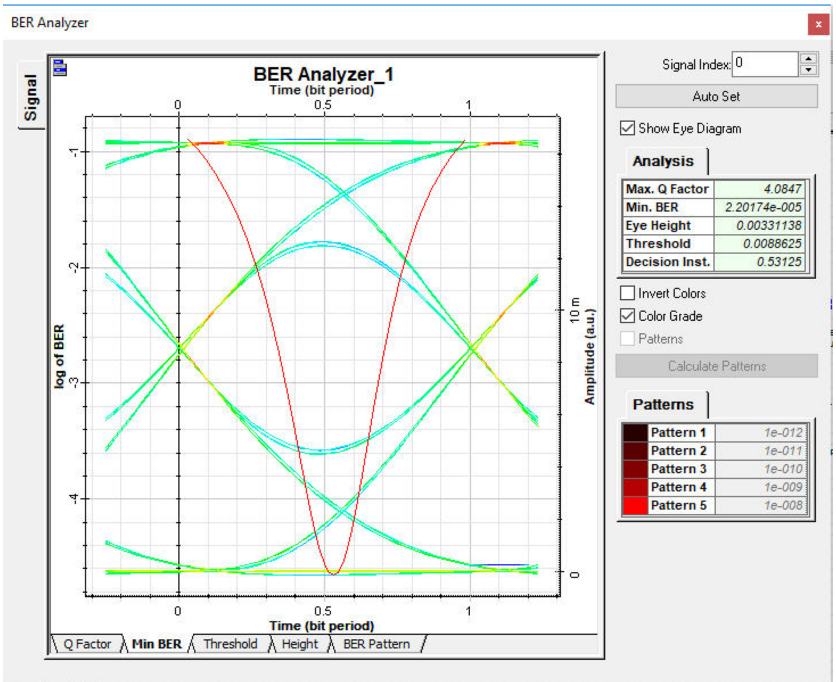

Figure-5. The eye diagram of the system, which clarifies the superior performance since the eye diagram still stays open after the transmission of data through an OWC channel.

6. CONCLUSIONS

This article has been investigated a new model of an optical wireless communication system to transport NRZ signal with a 320 Mbps data rate using an optical phase modulator driven by 60 GHz mm-wave signal to be transferred through the wireless channel. The digital electrical signal has been transferred to an optical form using an intensity modulation. In our scheme, the receiver device has not had an expensive component such as an optical amplifier, electrical amplifier and optical filter; it is just having a PIN photodiode and low pass Bessel filter. Therefore, our proposed OWC system has low installation cost and RF interference for high data transmission. The simulation results show that the performance of NRZ with the intensity modulation and phase modulator is better achieved with 320 Mbps data rate and 10m distance between transmitter and receiver. The proposed OWC system has a good BER performance and opening eye diagram. Our proposed system has been designed by using Optisystem software, which is a good platform for the researchers to design OWC system and then it can be implemented for the experimentations with minimum effort, time and cost. Further investigation of utilization of phase modulation and mm-wave frequencies in various kinds of optical source such as LED. Also, the background noise for real environment is yet to be studied.

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