BER Characteristic of Ground-to-Train Communication System Using Free-Space Optics Technology

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ABSTRACT
We propose a ground-to-train communication system using free-space optics between a train and the ground. In this paper, we evaluate BER characteristic in outdoor experiment using test train. The experimental results lead to the conclusion that the proposed system is a promising candidate for train communication from the viewpoint of BER characteristic.
Keywords: Free-space optics, Visible light communication, Train communication, Spread optical beam, BER characteristic.

1. INTRODUCTION

In recent years, the environment of the ubiquitous society has been developed by rapid expansion of high-speed communication infrastructure such as Asymmetric Digital Subscriber Line (ADSL) and Fiber To The Home (FTTH). Meanwhile, there is a high demand for the infrastructure to provide enough service to customers in a train. Leaky CoaXial cable (LCX) [1] and millimeter-wave have been used for wireless communication between a train and the ground [2]. However, these systems cannot provide high-speed data transmission in the moving train.

The equipments of free-space optical communication (FSO) such as Laser Diode (LD) and Light Emitting Diode (LED) are being developed rapidly, and it is possible to achieve high-speed communication with these equipments. Since frequency of lightwave is very high, FSO is suitable for high-speed communication [3,4]. Furthermore, outdoor application using FSO and solutions of outdoor applications (especially atmospheric turbulence and weather attenuation) has been studied [7,8,9]. Hence, we consider that outdoor application using FSO will become widely used.

We propose a ground-to-train communication system using free-space optics technology between a train and the ground [10]. In the proposed system, a cylindrical concave lens spreads the incoming beam from LD horizontally to form a wide fan-shaped beam. The fan-shaped beam is projected to a train and the width of the projected beam is 25 meters which is equal to the length of a typical bullet-train car. Therefore, the train can continuously keep a communication link to the ground.

We analyzed received Signal-to-Noise Ratio (SNR) and continuousness of received signal experimentally. We found that a sufficient SNR at stasis could be obtained for 25 meter train length, and that a train can keep a communication link continuously for a 25 meter train length. However, Bit Error Rate (BER) characteristic of this system has not been investigated yet. In this paper, we investigate BER characteristic of this system in outdoor experiment using test train.

The rest of the paper is organized as follows. In section 2, we describe optical design of transmitter. In section 3, we describe optical design of receiver. In section 4, we describe the proposed system model. In section 5, we evaluate BER characteristic of proposed system experimentally. Finally, the conclusions are given in section 6.

2. OPTICAL DESIGN OF TRANSMITTER

LD is a device that emits the light by induced emission and laser oscillation and outputs the coherent light. The light of LD has isolated wavelength and high directivity, and the transmission power of LD is higher than that of LED [5,6]. Even though the light of LD has high directivity, the width of the beam projected to a train is diffused and the sufficient received optical power cannot be obtained. To obtain sufficient power of LD at the train, a variable NA lens which can change focal distance is attached in front of the LD. Since the incident beam angle from LD can be adjusted, the transmitted power can be controlled locally. The vertical beam angle of this LD is set to between 0.1 and 5.72 degrees.

Moreover, we need to spread the incoming beam from LD, using optical lens in order to expand the length of communication area. There are many types of lens such as spherical lens, paraboloidal lens, and cylindrical lens. Among various types, cylindrical lens have a shape of cylinder, and can bring about an effect of lens in one direction. Since horizontally spread beam is projected to a bullet-train car in the proposed system, we select cylindrical concave lens which spreads horizontally the incoming beam from LD to form a wide fan-shaped

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beam. Furthermore, it sometimes happens that reflection and attenuation on this lens is occurred. However, since the size of lens is small and there is very small reflection and attenuation, transmission power of LD is little influenced by this lens. In this paper, we select horizontal beam angle 20 degrees.

Figure 1 describes concept of LD which is equipped with variable NA lens and the effect of cylindrical concave lens, which is included in optical design of transmitter, and photograph of optical spread beam.

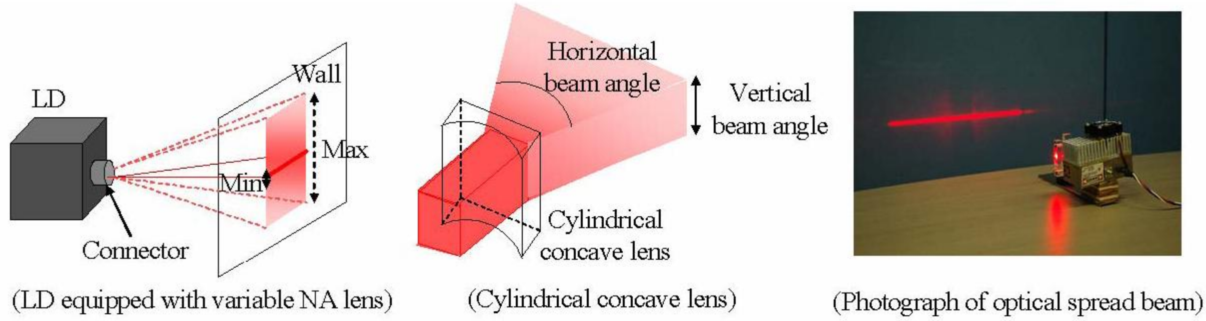

Figure 1. Optical design of transmitter.

3. OPTICAL DESIGN OF RECEIVER

Optical lens which works as optical concentrator is attached in front of sensor of Avalanche Photo Diode (APD), and the increase of received optical power can be expected. Since it is easy to be attached in front of sensor of APD and the light can be concentrated on this point, we select hemispherical lens which works as optical concentrator. However, there is a problem that this lens has a directivity angle. In this research, Full Width at Half Maximum (FWHM) of lens is 17.6 degrees.

Moreover, it is useful that optical filter is attached in front of APD to get through the light which has the particular wavelength. However, if this filter that has a narrow bandwidth is tilted for the incoming light, wavelength of the light which pass through this filter is changed and the light which has the particular wavelength cannot pass through. In order to solve the problem, if we use optical filter which has a wide bandwidth, it is possible that the light which has the particular wavelength can pass through to some extent.

Figure 2 describes photograph of APD which is equipped with optical lens and the spectral data of optical filter, which is included in optical design of receiver, and photograph of receiver.

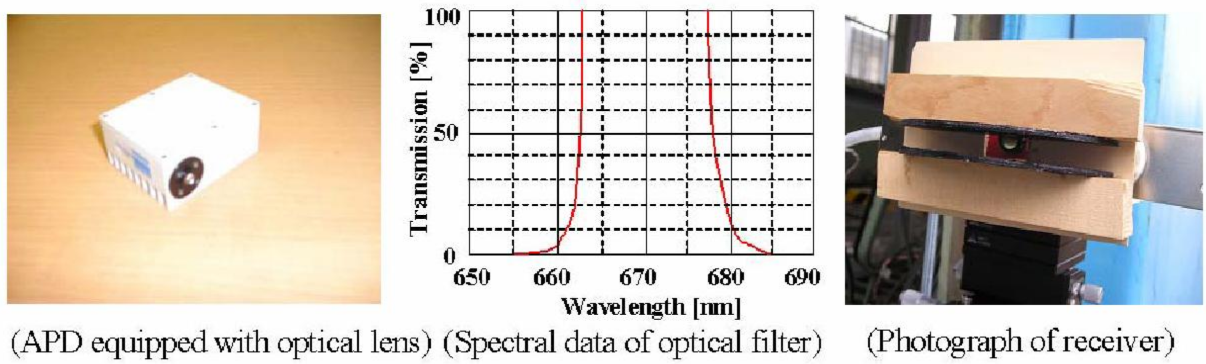

Figure 2. Optical design of receiver.

4. SYSTEM MODEL

The proposed system model is illustrated in Figure 3. The width of the projected beam is 25 meters which is equal to the length of a typical bullet-train car. Since the horizontal distance between a bullet-train and LCX is 1.9 meters, if it is possible to communicate at this distance, LD and APD can be utilized instead of LCX. Hence, the horizontal distance between train and ground is 2 meters (the height of LD and APD is the same). The down-link communication from the ground to the train and the up-link communication from the train to the ground use the same transmitter (LD) and receiver (APD) so that the speed of down-link and up-link are equally designed. According to [10], it was found that the optimal horizontal beam angle is 20 degrees.

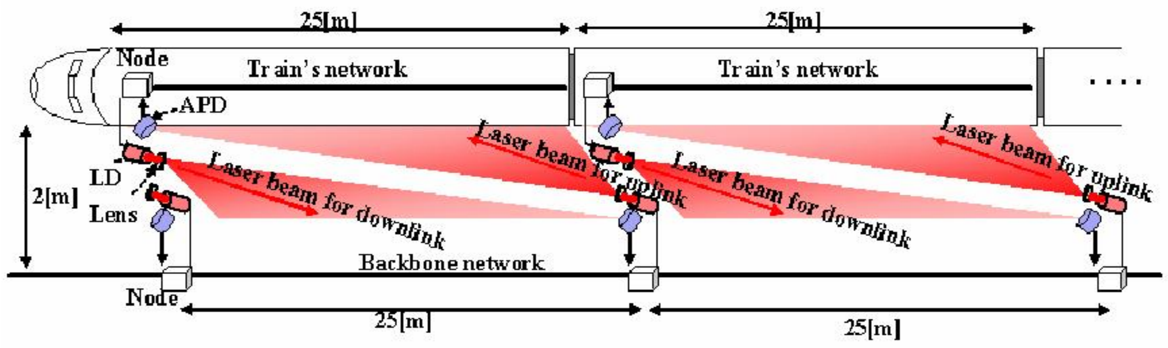

Figure 3. Proposed system model.

5. EXPERIMENTAL RESULTS

In this section, we evaluate BER characteristic experimentally. We conducted the outdoor experiment using test train, and measured BER characteristic for three bit rates such as 60, 100, 120 Mbps, between 0 meter point and 25 meter point at 5 meter interval using test train. Figure 4 describes concept and photograph of outdoor experiment using test train, and Table 1 shows experimental setup. In this experiment, a lens which works as optical concentrator and an interference filter are attached in front of APD. The length of platform is 20 meters and that of test train is 19.6 meters. The width of the projected beam is 25 meters, the horizontal distance between LD and APD is 2 meters. Horizontal beam angle is 20 degrees, and the tipped angle of APD is 7 degrees because FWHM of lens is 17.3 degrees. Figure 5 shows experimental results of the outdoor experiment.

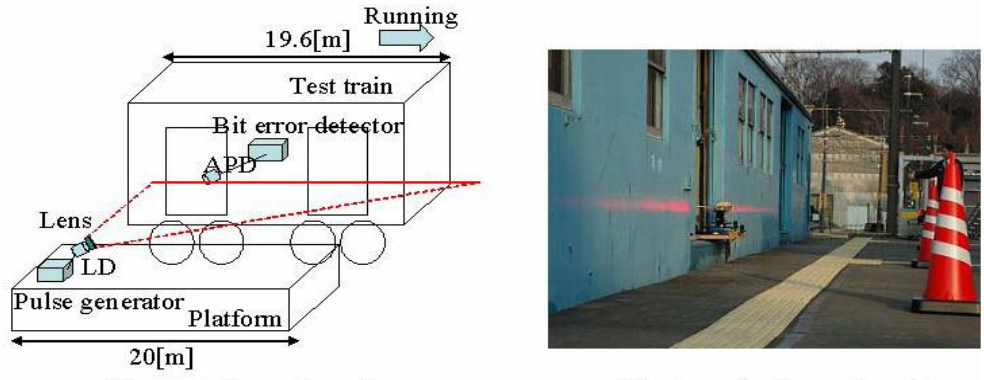

Figure 4. Outdoor experiment using test train.

Table 1 . Experimental setup

Bit Rate	100 Mbps
Transmitted power of LD	100 mW
Wavelength of the light from LD	670 nm
Frequency of the light from LD	400 MHz
Horizontal beam angle (with cylindrical concave lens)	20 degrees
Vertical beam angle	0.1/0.3/0.5 degrees
Receiver	APD with optical lens
Angle of receiver	7 degrees
FWHM of optical concentrator	17.3 degrees
Optical filter	Interference filter
Weather	Fine day
Received signal amplitude of ambient noise	40 mV

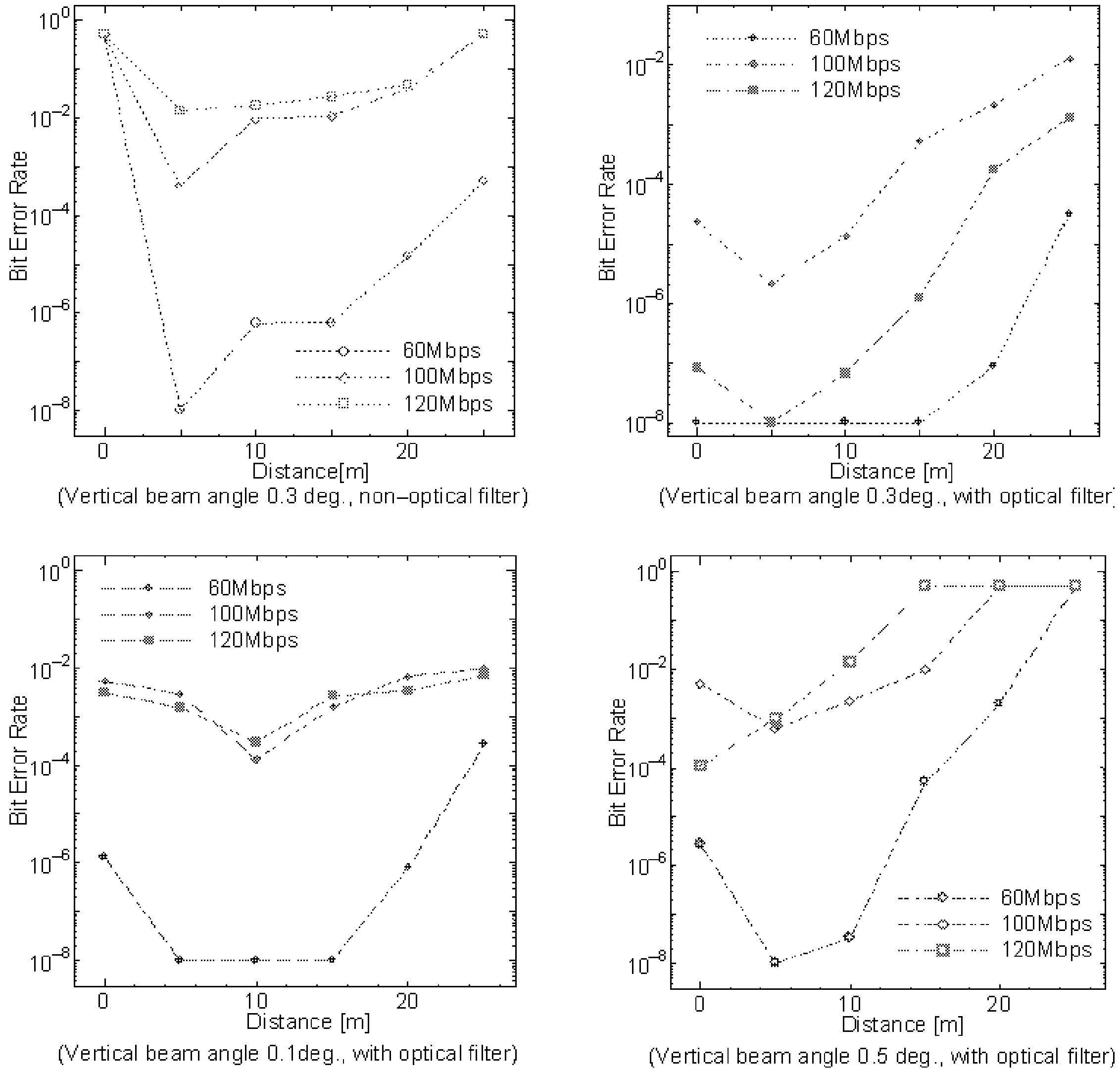

Figure 5. Experimental results.

It can be seen from these results that BER characteristic become worse gradually as the distance becomes longer between 5 meter point and 25 meter point. Because of these results, we can figure out three points. First, we can find that BER characteristic of 0 meter point is worse than that of 5 meter point. We think that this results from the effect of directivity angle of optical lens on sensor of APD. Second, compared with the case of using non-optical filter, BER characteristic using optical filter is better because optical filter can get through the light which has the particular wavelength. Finally, we can find that the optimal value of vertical beam angle is 0.3 degrees. We think that optical lens on sensor of APD is easy to collect the light due to the expansion of vertical beam angle.

Moreover, weather of the outdoor experiment was fine day. But, if weather of the experiment is rainy or snow, propagation loss is increased by weather condition [7,8]. Therefore, we need to consider weather attenuation as the future work.

6. CONCLUSIONS

In this paper, we investigate BER characteristic of ground-to-train communication system using free-space optics technology in outdoor experiment using test train. It was shown from the experimental results that the optimal value of vertical beam angle was 0.3 degrees and optical filter on sensor of APD was effective. Moreover, we confirmed that the proposed system is a promising candidate for train communication from the viewpoint of BER characteristic. As the future issues and problems, we'll investigate the improvement of BER as the distance becomes longer, and consider weather attenuation. Furthermore, we'll control the handover which occurs at the time of train's moving between the communication areas.

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