Vehicular Visible Light Communications with A Solar Panel Receiver

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ABSTRACT

The wide availability of light-emitting diode (LED)-based light sources makes possible the use of visible light communication (VLC) for both indoor and vehicular wireless connectivity. Earlier works on VLC have predominantly used photodetectors as receivers. It is also possible to utilize solar panels as receivers. In this paper, we present an experimental performance evaluation of a vehicular VLC system with a truck headlight as the transmitter and a solar panel as the receiver. First, we characterize the frequency response of two different solar panels and measure their bandwidth. Then, we present the performance of the vehicular VLC system in terms of data rate, signal-to-noise ratio (SNR), and eye diagrams.

KEYWORDS

Vehicular visible light communications, Solar panel, LED headlight.

ACKNOWLEDGMENT

This work was funded by the European Union's Horizon 2020 research and innovation program under the Marie Skłodowska Curie grant agreement ENLIGHTEM No. 814215.

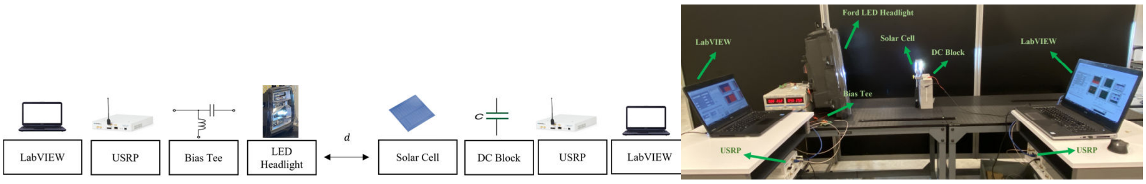
1 INTRODUCTION

Visible Light Communication (VLC) utilizes visible optical bands for high-speed data transmission and provides an alternative solution to radio frequency counterparts [1]. The wide availability of light emitting diode (LED)-based light sources makes possible the use of VLC for both indoor and vehicular connectivity. Earlier works on VLC have predominantly used photodetectors as receivers. It is also possible to utilize solar panels as receivers, which brings the advantage of combining communication and energy harvesting functionalities [2].

For indoor applications, the use of solar panels as VLC receivers is well-investigated in the literature. For instance, in [3], and [4] the authors experimentally investigated the performance of indoor VLC systems with multi-crystalline silicon solar panels used as receivers. They implemented the dual functionality of data transmission and energy harvesting and reported data rates up to 17.5 Mbps.

In [5], the authors conducted outdoor experiments with silicon solar panels and reported transmission distances up to 6.75 m while achieving a data rate of 50 kbps. The work in [6] reported a system performance enhancement mechanism using a pair of focusing lenses positioned after the LED and before the silicon solar panel receiver and reported a data rate of 15 Mbps.

The current literature reveals a research gap regarding the utilization of solar panels as receivers in vehicular VLC systems. Particularly, there is a lack of studies exploring the use of vehicular headlights as transmitters in such systems. In our setup, we utilize an LED-based truck headlight as the



(a) (b)

Figure 1: Solar panel-based vehicular VLC system(a) block diagram, (b) experimental setup.

transmitter and a solar panel as the receiver. We experimentally evaluate the bandwidth, data rate, and signal-to-noise ratio (SNR) of the vehicular VLC system using solar panels of two different types including Gallium Arsenide (GaAs) and Monocrystalline solar panels.

The rest of the paper is organized as follows: Section II introduces the system model. Section III presents experimental results and discussions on performance. Finally, Section IV provides the conclusion.

2 SYSTEM MODEL

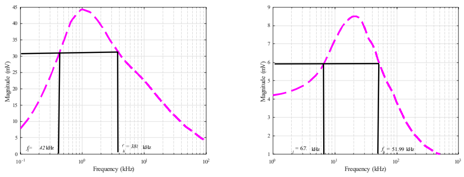
2.1 Experimental Set-up

In Fig. 1, we present the experimental setup for the vehicular VLC system under consideration. At the transmitter side, a Universal Software Radio Peripheral (USRP) is used to generate on-off keying (OOK) modulated signal around 100 kHz frequency. A bias tee is used to combine the modulated signal and DC bias voltage. This drives the LED-based low-beam truck headlight. The transmitter used in this setup is a Ford F-max low-beam LED headlight, which possesses a luminous flux of 750 lm. At the receiver side, a solar panel is used to collect the optical intensity and convert it into an electrical current. The solar panel is connected to the receiver USRP through a DC block circuit.

2.2 Bandwidth Characterization of Solar Panels

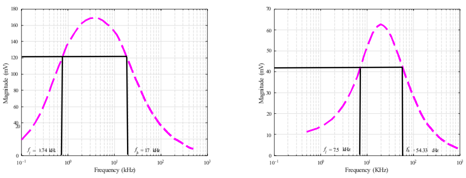
As receivers, we use two solar panels including GaAs with the size of $80 \times 40 mm^2$ and conversion efficiency of 0.345, and a monocrystalline solar panel with the size of $40 \times 40 mm^2$ and the conversion efficiency of 0.22.

Solar panels' utilization as VLC receivers depends on the bandwidth that they can support. Therefore, we first obtained the frequency response of solar panels and measured their bandwidths. To accomplish this, we utilized a low-frequency bias tee with a capacitance of 33 microfarads and an inductance of 1439 microhenries to capture the lower part of the solar panels' frequency response. Additionally, we utilized a high-frequency bias tee with the same capacitance of 33 microfarads but with an inductance of 26 microhenries to examine the upper part of the solar panels' frequency response. Fig. 2 illustrates the frequency spectrum of the GaAs solar panel utilizing both a low-frequency biased bias tee (Fig. 2.a) and a high-frequency biased bias tee (Fig. 2.b). Similarly, Fig. 3 displays the frequency spectrum of the Monocrystalline solar panel using the low-frequency biased bias tee (Fig. 3.a) and the high-frequency biased bias tee (Fig. 3.b). For the monocrystalline solar panel, the measured bandwidth is 53.6



(a) (b)

Figure 2: Frequency response of GaAs solar panel for (a) low-frequency bias tee, (b) high-frequency bias tee



(a) (b)

Figure 3: Frequency response of monocrystalline solar panel for (a) low-frequency bias tee, (b) high-frequency bias tee.

Table 1: Experimental results

	Monocrystalline		GaAs	
Distance (cm)	Data rate (kbps)	SNR (dB)	Data rate (kbps)	SNR (dB)
50	24.4	30	24	27
70	24.4	27	24	11
90	24	23	No signal	No signal
110	24	14	No signal	No signal

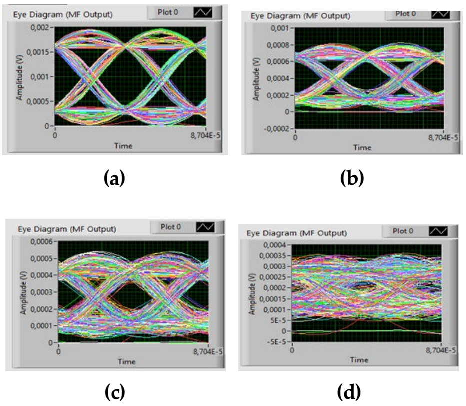


Figure 4: Eye diagram of the monocrystalline-based receiver for different distances of (a) 50 cm, (b) 70 cm, (c) 90 cm, and (d) 110 cm.

kHz, while for the GaAs solar panel, it is 51.6 kHz. These measurements indicate the range of frequencies at which the solar panels can effectively receive and transmit data through VLC.

3 PERFORMANCE MEASUREMENTS

The measurements for data rate and SNR were performed at varying distances, ranging from 50 cm to 110 cm. Throughout all the measurements, an up-sampling factor of 8 was utilized. The noise power remains consistent across all distances and shows minimal variation. Specifically, for the monocrystalline solar panel, the noise power level is approximately -93 dB, while for the GaAs solar panel, it is around -90 dB, which is almost the same.

The experimental results are provided in Table I and reveal notable variations in data rate and SNR for the monocrystalline solar panel and GaAs solar panel-based receivers at different distances. When utilizing the monocrystalline solar panel, a data rate of around 24 kbps is achieved at all distances under consideration with some slight changes for 90 cm and 110 cm. The SNR levels are measured at 30 dB, 27 dB, 23 dB, and 14 dB for distances of 50 cm, 70 cm, 90 cm, and 110 cm, respectively.

In contrast, when employing the GaAs solar panel as the receiving unit, data rates of 24 kbps are achieved at distances of 50 cm and 70 cm. However, beyond this range, the received signal strength decreases significantly, leading to synchronization failure and rendering data transmission impossible. Specifically, the SNR is measured at 27 dB for a distance of 50 cm, but it drops to 11 dB at a distance of 70 cm. The SNR levels become extremely low for longer distances, making it unfeasible to transmit data reliably.

Based on the results, it can be concluded that the monocrystalline solar panel outperforms the GaAs solar panel as the receiving unit in terms of SNR and the strength of the received signal. This is mainly due to the fact that the monocrystalline solar panel used in this experiment exhibited a higher gain than the GaAs solar panel around 100 kHz where the modulated signal is based. It can be readily checked from Figs. 2 and 3 that the corresponding gains for GaAs and monocrystalline solar panels are respectively 4 mV, and 30 mV.

Fig. 4 presents the eye diagram of the receiver based on the monocrystalline solar panel for distances of 50 cm, 70 cm, 90 cm, and 110 cm, respectively. As the distance between the transmitter and receiver increases, the quality of the eye diagram deteriorates, hindering its ability to represent the received signal accurately. This degradation suggests that the noise originating from the solar panel-based receiver becomes increasingly dominant with distance.

4 CONCLUSION

In this paper, we investigated the feasibility of a vehicular VLC system with a solar panel receiver. Our frequency response measurements revealed that the electrical bandwidths are around 50 kHz. Although the bandwidths are relatively limited, these would be sufficient to support many safety-related functionalities in vehicle-to-vehicle communication. Our experimental results demonstrated that a data rate up to 24 kbps can be supported with SNR values in the range of 14-30 dB based on the transmission distance.

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