Vehicular Visible Light Communications: The Impact of Taillight Radiation Pattern

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***Abstract*—We investigate the path-loss of vehicular visible light communications based on the radiation pattern of a commercial car taillight. The measured pattern is incorporated into a ray-tracing model and simulation results indicate up to 4.2 dB variation in the path-loss compared with the Lambertian model.**

Keywords—Visible light communications, optical-path-loss, radiation pattern, Lambetian model

I. Introduction

Vehicular communications and its potential in reducing the number of road accidents is gaining more interest as part of the global intelligent transportation system (ITS). The widespread adoption of light emitting diodes, in automotive lightings such as head- and tail-lights (HLs and TLs), indicator lights, etc. makes the use of optical wireless communications (OWC) technology an interesting option in ITS [1]. The OWC technology, which cover the ultraviolet, visible and infrared bands, has the advantage of a large unregulated-bandwidth, immunity to the radio frequency (RF) induced interference, and high-level of security at the physical layer that can be used in certain application in order to reduce the pressure on the highly in demand RF spectrum [1].

As part of OWC, visible light communications (VLC) has become attractive for a number of applications including ITS. In VLC systems, as in any other communication links, channel modeling is very important since it will impact the link power budgets. The path loss (PL) can be determined via ray-tracing or experimental measurements. Extensive experimental and simulation studies on the VLC link PL have been reported in the literature [2]. In vehicular VLC, both HLs and TLs can be employed as the optical transmitters , however, most reported works on vehicular VLC have focused on HLs-based transmitters [3-5]. In [3], a PL model for vehicular VLC using a HL-based transmitter was proposed based on ray-tracing using OpticStudio®. Whereas in [4, 5], a measured HL radiation pattern model was adopted and the relationship between the bit error rate (BER) and the transmission span was developed. However, only few works have considered the use of TLs in vehicular VLC [6, 7].

In this paper, we investigate the PL in vehicular VLC based on the real measured radiation pattern of the TL and compare it with the widely adopted Lambertian model. Specifically, we model the TL of a commercial vehicle and perform the simulations based on non-sequential ray-tracing in OpticStudio® [3]. Based on this simulation methodology, which was also used in the development of IEEE 802.15.13 and 802.11bb reference channel models [8], [9], it is possible to integrate the measured radiation pattern of the TL. In the experimental measurements, we first obtain the optical radiation pattern of the TL under consideration by measuring the received power as function of the TL's irradiance angle. The measured radiation pattern is then imported into the simulation platform and the channel PL is obtained to illustrate the effect of radiation pattern's asymmetry compared with Lambertian model.

The remainder of the paper is organized as follows. In Section II, we explain the raytracing methodology used in our study. Section III describes the experimental setup results. Finally, conclusions are given in Section IV.

II. Simulation Methodology

The main steps in channel modeling adopted in this work are outlined as follows. First, we create a three-dimentional (3D) simulation model of the test environment for OpticStudio® and import the imbedded CAD models of the objects. The coating materials in CAD objects are defined in the simulation platform, where it is possible to consider the wavelength-dependent reflectance [9] as well as the scatter fraction. Next, the light source specifications such as the optical power, radiation pattern, orientations and number of emitted rays are defined as well as the active area, angular field-of-view and orientations for the receiver are defined. Next, non-sequential ray tracing is performed to obtain the path length and the power of each ray emitted from the light source and received at the photodetector. These information are then imported into MATLAB® for processing. Finally, the channel impulse response (CIR) is obtained as $h(t)=\sum_{k=1}^{M} P_k\,\delta(t-\tau_k)$, where M is the number of rays received by the photodetector and δ is the Dirac delta function. Here, P_k and τ_k, respectively denote the power and the propagation delay of the k^{th} ray and $k=1,2,\ldots,M$. The PL can be then calculated by $PL = 10\log_{10}\left(\int_0^{\infty} h(t)dt\right)$.

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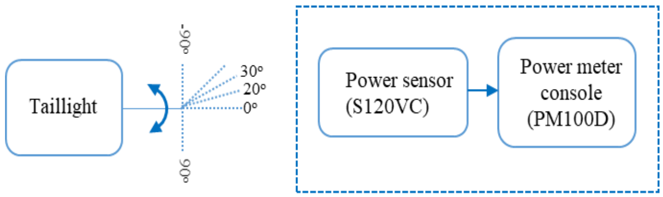

Fig. 1. Schematic diagram of experiment setup.

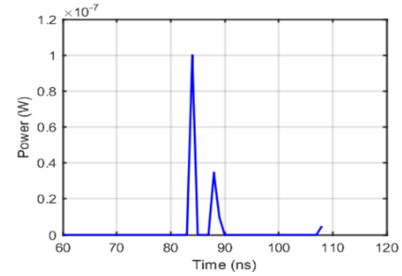

Fig. 3. CIR at 25 m transmission distance.

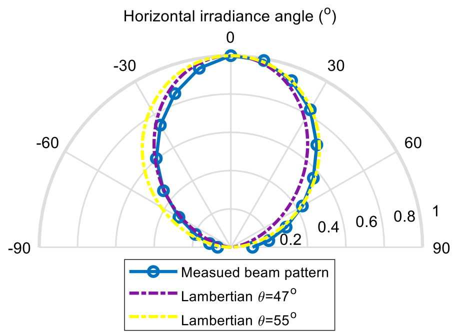

Fig. 2. Measured and Lambertian radiation pattern.

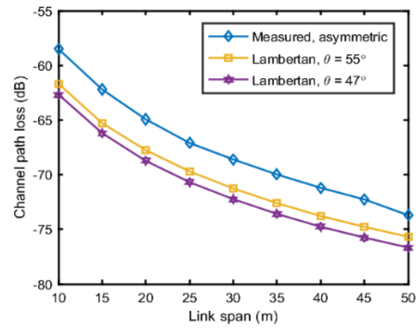

Fig. 4. Simulated and measured path loss.

III. Experimental Setup and Results

To empirically obtain the optical radiation patterns of TL under consideration (Audi A5 S5 N/S LED Outer TL facelift), we use an optical power meter (Thorlabs PM100D) to measure the received optical power over a fixed transmission distance of 1 m for the TL's irradiance angle in the range of -90º to +90º, see Fig. 1. The measured radiation pattern, see Fig. 2, is imported to OpticStudio platform to determine the path-loss. Interestingly, the half-power angle θ (i.e., the angle at which the received power is reduced by half) from the measurements is found to be different at the two sides of the beam axis, i.e., at the right and left sides we have θ = 55º and 47º, respectively. In Figure 2, we present the measured radiation pattern along with benchmarking Lambertian curves for θ = 47º and 55º. It is obvious that the Lambertian model is not able to capture the asymmetrical measured radition pattern. It is observed from Fig. 3 that there is a non-neglible second peak resulting from ground reflections . In Fig.4, we present path-loss as function of transmission distance. The path-loss for Lambertian models for θ = 47º and 55º are obtained based on simulations. It is observed that the asymmetry of TL's radiation pattern influences the channel path-loss. For example, for a transmission distance of 25 m, the measured path-loss is -67 dB, higher by~3 and ~4 dB compared with Lambertian model with θ of 55º and 47º, respectively.

IV. Conclusion

We investigated the impact of optical radiation pattern of a vehicle's TL obtained from empirical measurements and Lambertian model on the optical PL of the VVLC channel. Measurements revealed that, the radiation pattern of TLs may not be symmetrical, depending on the TL type and has a significant impact on the PL compared with Lambertian model.

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