

# Channel Characterization for Intra-Wagon Communication at 60 and 300 GHz Bands

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**Abstract**—In this paper, the intra-wagon channels at 60 and 300 GHz bands are characterized through measurement-validated ray-tracing (RT) simulations. To begin with, an in-house-developed three-dimensional RT simulator is calibrated and validated by a series of millimeter-wave and Terahertz channel measurements inside a high-speed train wagon. Then, the validated RT simulator is used to conduct extensive simulations with different transmitter (Tx) and receiver deployments. At low frequencies, the channel is strongly influenced by the line of sight (LOS), and therefore, is usually classified into LOS and non-LOS (NLOS) regions. However, the simulation results at 60 and 300 GHz bands show that the first-order reflection also imposes a significant impact on the channel characteristics. This motivates us to further classify the NLOS region into light-NLOS (L-NLOS) and deep-NLOS (D-NLOS) according to the existence of the first-order reflection. Through analyzing the area ratios of LOS, L-NLOS, and D-NLOS regions, we evaluate the Tx deployment strategies and suggest the optimum one. Based on RT simulation results, totally 12 cases (three propagation regions with two Tx deployments at two frequencies) are characterized in terms of path loss, shadow fading, root-mean-square delay spread, Rician  $K$ -factor, azimuth/elevation angular spread of arrival/departure, cross-polarization ratio, and their cross correlations. All these parameters are fed into the 3GPP-like quasi-deterministic radio channel generator (QuaDRiG). The good agreement between QuaDRiG and RT proves that the 13 tables provided in this paper effectively parameterize the intra-wagon scenario for the standard channel model family. These results provide valuable insights into the system design and evaluation for intra-wagon communications.

**Index Terms**—Channel characterization, intra-wagon, mmWave, railway communications, ray-tracing, smart rail mobility, THz.

## I. INTRODUCTION

**I**N THE vision of “smart rail mobility”, railway infrastructure, trains, travelers and goods will be increasingly interconnected [1]. Correspondingly, a seamless high-data-rate wireless connectivity with up to dozens of GHz bandwidth will be required to provide various bandwidth intensive applications, such as on-board and wayside high definition (HD) video surveillance, on-board real-time high-data rate connectivity, train operation information, real-time train dispatching HD video, and journey information [2]. Thus, developing millimeter wave (mmWave) and terahertz (THz) communications for railway is attracting increasingly more attention nowadays [3]. Among the five “smart rail mobility” scenarios [2], the intra-wagon scenario describes the links between access points (APs) in the wagon and the transceivers of passengers’ user equipment (UE) or sensors inside a wagon. Because of the relatively low mobility, this scenario is very suitable for mmWave and THz communications.

In principle, there are two possible methods to realize high-data rate transmission inside a wagon. One is aiming at systems at the 60 GHz band with 7 GHz spectrum dedicated to the mobile applications worldwide. The other is to adopt moderate spectral efficiencies with ultra-high bandwidths beyond 20 GHz, which can be identified only in the THz frequency range, i.e., beyond 300 GHz [4]. Thus, in order to support the design and development of the intra-wagon mmWave and THz communication systems, it is necessary to characterize the intra-wagon channels both at 60 GHz and 300 GHz bands.

In the existing research, most of the efforts were made on various train-to-infrastructure channels [5], such as viaducts [5], cuts [6], crossing bridges [7], tunnels [8], [9], and train stations [10]. However, due to totally incomparable environments, the aforementioned studies can be hardly transferred to the intra-wagon channel. In fact, because of particular geometrical and physical characteristics of a wagon, the intra-wagon channel is even different from other intra-vehicle environments, e.g., intra-car [11], [12], intra-plane [13], [14], intra-ship [15], and intra-container [16]. Thus, it is of importance to characterize the intra-wagon channels through measurements or simulations

Manuscript received November 7, 2018; revised January 23, 2019; accepted March 10, 2019. Date of publication March 26, 2019; date of current version June 18, 2019. This work was supported in part by the Beijing Natural Science Foundation under Grant L1610099, in part by the National Natural Science Foundation of China under Grants 61771036, U1834210, and 61725101, in part by Fundamental Research Funds for the Central Universities under Grant 2018SC030, in part by State Key Lab of Rail Traffic Control and Safety Project under Grants RCS2018GZ0006 and RCS2017ZT008, and in part by Alexander von Humboldt Foundation. The review of this paper was coordinated by Prof. D. B. da Costa. (Corresponding author: Bile Peng.)

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Digital Object Identifier 10.1109/TVT.2019.2907606

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