Automotive millimeter-wave wireless harness utilizing ceiling reflector

Ryo Yamada \(^1\), and Akihiro Kajiwara\(^{a)\}

\(^1\)Graduate School of Environment Engineering, University of Kitakyushu
1-1, Hibikino, Wakamatusu-ku, Kitakyushu, Fukuoka 808-0135, Japan
\(^{a)\} \text{kajiwara@kitakyu-u.ac.jp}

**Abstract:** This paper is concerned with automotive networks and suggests the use of wireless signal to replace current wired signal between some ECU nodes for the improvement of fuel efficiency and reduction of fossil fuel usage. Considering the wireless connection channel, it would be blocked by passenger’s body and seat, for example, thereby resulting in channel deterioration. This paper presents a wireless approach based on automotive ceiling reflection where the ceiling simply performs as reflector. The ceiling will be able to offer stable wireless link for all the nodes. Measurement was conducted in 60 GHz band and the results are compared with conventional wireless approach. As a result, our suggested approach is found not to be affected by passengers and seat.

**Keywords:** Millimeter-wave, automobile, wireless harness, reflector

**Classification:** Wireless Communication Technologies

**References**

[1] K. Akingbehin, et al., “A Hybrid Wireless Harness for Automotive Applications,” Proc. of 3rd International conference on Computer and Information Science, Aug. 2004.

[2] Y. Katayama, et al., “Experimental evaluation of in-vehicular UWB radio propagation characteristics,” IEICE Trans. on Comm. B, Vol.J89-B, No.9, pp.1815-1819, Sep. 2006.

[3] T. Kobayashi, “Measurements and Characterization of Ultra Wideband Propagation Channels in a Passenger-Car Compartment,” IEICE Trans. on Fundamentals, Vol.E89-A, No.11, pp.3089-3094, Nov. 2011

[4] R. Nakamura, A. Kajiwara, “Intra-vehicle wideband radio propagation characteristics at 60 GHz band,” IEICE Trans. on Comm., Vol.J95-B, No.2, pp.302-308, Feb. 2012.

[5] F. Bellens, et al., “Characterization and modeling of ultra-wideband wireless channels for intra-vehicle communications,” IEEE Trans. on VT, Vol.62, No.2, pp.302-308, Jan. 2013.

[6] A. Chandra, T. Mikulasek, J. Blumenstein, A. Prokes, “60 GHz MMW channel measurements inside a bus,” Proc. of NTMS, pp.1-5, Nov. 2016.
1 Introduction

This paper is concerned with automotive networks and suggests the use of wireless signal to replace current wired signal between some ECU (electronic control units) nodes for the improvement of fuel efficiency and reduction of fossil fuel usage. It is well known that there are over 100 ECUs controlling electrical systems. The weight of ECU and distribution wire harness is approximately 30~50 kg and the wired inter-connection is becoming increasingly complicated. Several studies have been so far conducted on wireless harness approach which offers several advantages such as reduced weight and easy inter-connection setting; A hybrid wireless harness approach was presented in [1] and the effect of passengers on wireless channel was discussed in [2]-[6]. The wireless approach in engine compartment was also investigated and the deterioration has been shown to be relatively small in [7]. However, the wireless channel, especially in millimeter-wave band, is more susceptible to LOS (line-of-sight) obstruction and the path loss is a major hindrance for the channel. Extra transmit power might be one of the solutions for a given fade margin, but it may cause interference to the other channels inside and outside the automobile. Therefore, it is a prominent challenge to establish stable wireless link to the nodes. To solve the above problem, we suggest the wireless link connection between the nodes (especially for two ECU domains of entertainment and body control) utilizing ceiling reflection. The ceiling will offer stable bypass links (establishing detour link connection of transmitter-reflector-receiver) regardless of the number of passengers. Measurement was conducted in 60 GHz band and the results are also compared with conventional wireless approach. As a result, our suggested approach is found not to be deteriorated by passenger’s body and seat.

2 Automotive wireless harness

Fig.1(a) shows an example of wireless connection approach simply replacing the wired connection between the nodes. It is noted that we consider two ECU domains of entertainment and body control except for the power-train domain from the viewpoint of safety such as delay and fail-safe function. The approach, hereinafter called conventional wireless approach, offers the following advantages:

・ Reduced automotive weight due to replacement of wires with wireless signals.
・ Easy inter-connection setting and easier maintenance of ECUs.

However, the wireless link, particularly in an automobile small cabin, will be more subject to significant path loss and shadowing by passenger’s body. Considerable extra transmit power would be required to meet a given fade margin, thereby causing interference to the other channels inside and outside the automobile [4][7]. RAKE reception, which is designed for the purpose to counter the effect of multipath fading, would mitigate the path loss, but instead, the system complexity
may be unacceptable to all the nodes [3]. Therefore, a simple wireless approach is required to suppress the channel deterioration due to LOS obstruction. Our suggested approach is shown in Fig.1(b) where the transmit and receive antennas of each node are pointed straight up towards the ceiling. The channel may experience some reflection loss at the ceiling or roof, but the loss will be not so significant as compared with the LOS blockage.

3 Measurement results

A. Measurement set-up

A 5-door hatchback automobile (Toyota’s Prius α ®) was used for measurement. The 10 dBi gain directional antenna with 0 dBm transmit power was installed at the center console assuming the main ECU node, while the same gain antenna was installed in order at 4×9 points in a grid pattern as shown in Fig.2(a). The measurement in 60 GHz band was conducted with a vector network analyzer (Keysight: E8363B) and MMW extension modules (OML: 60-90 GHz) because the VNA provides a precise calibration capability and a wide dynamic range. The VNA was placed outside the automobile to avoid the effect of EMI noise and each channel measurement was conducted in the automobile as shown in Fig.2(b). The extension modules make the channel configuration easier. The antennas were set at a height of 50 cm from the automotive floor due to restrictions on mounting jigs including antenna and waveguide. The directional antennas were placed to face each other in conventional wireless approach [2][4], while the antennas of our suggested approach were pointed straight up as shown in Fig.2(b). Automotive roof has generally two-layer structure approximately 2.5cm spaced; outer is metal roof panel and inner is composite material ceiling panel. However, remarkable difference due to the structure was not seen in the received range profile because of the small two-layer spacing.

B. Received power and delay spread

In multipath fading channel such as intra-automobile, the delay spread is one of
the important parameters together with the path loss, which limits the transmission data rate and multipath fading resistance. The measurement of delay spread was therefore conducted using the 10dBi gain directional antenna [4]. The effects of passengers on the received power and delay spread are investigated only about the two receive antenna A and B shown in Fig.2(c). This is because the antenna A and B would be more susceptible to the multipath from nearby pillar, so-called B-pillar and C-pillar, respectively. The seat number represents the order in which the five passengers sit. Firstly, the received power as a function of passengers is shown in Fig. 2(d). It is seen for the two receive antennas that the power is nearly independent on the passengers. Small difference of less than 5dB in the received power would be caused by some multipath components scattered by the passenger’s body. For the conventional approach, however, the received power is observed to be approximately 15~20dB attenuated by the passengers. Please be noted that all the receiver positions have not always normal reflection path on the ceiling because of the handles, lights and rearview mirror attached on the ceiling. Secondly, the RMS delay spread is shown in Fig.2(e). The delay spread is seen to be decreased with the number of passengers since the multipath components are more attenuated by scattering in the passenger’s body. There is also no remarkable difference with conventional approach. As mentioned above, the received power at the antenna A and B does not change largely regardless of the passengers. It may therefore be important to discuss the received power at another points. Therefore, the received range profiles for ceiling reflection approach were measured at various antenna positions for a given transmit antenna. Please note that passengers were not considered due to the following reasons:(1) the effect of passengers would be small unlike conventional wireless approach, (2) the measurement considering passengers is not so easy because of the complicated wiring from the VNA to each antenna, and besides, some measurements must be taken by placing the receive antenna on the seat as shown in Fig.2(a). The spatial distribution of received power on the horizontal plane is shown on the color map in Fig.3(a). The received power is -65~60 dBm in the vicinity of the transmit antenna, while -80~75 dBm at the other points including trunk room which does not exhibit explicit dependence on distance. Some difference is seen due to the difference in path length from the transmitter to receiver via ceiling. Fig.3(b) shows that the spatial distribution of delay spread is approximately 6~9 ns. Some increased delay spread is seen for the vicinity of dashboard and A-pillar because of some multipaths from rear-view mirror and sun visor.

(a) Measurement point layout (4×9 receive antennas)
Fig2. Effect of passenger on received power and delay spread
4 Conclusions

This paper has suggested a wireless connection approach based on automotive ceiling reflection where the ceiling simply performs as reflector. The ceiling would offer stable channel for automotive wireless networks to interconnect entertainment and body control systems and to perform network maintenance. Measurement was conducted in 60 GHz band where the effects of passengers on the received power and delay spread have been investigated and the results have also been compared with conventional approach. As a result, our suggested approach was found not to be largely affected by multipath fading and to be stable robust to passengers. As our future work, additional measurements will be conducted on the other automotive models such as minivan and station wagon.

Finally, we envision that the approach will contribute to the reduced automotive weight and easy inter-connection setting.