Microwave Radio Propagation in Automobile Engine Compartment

Hirokazu Kamoda, Susumu Ano, Shoichi Kitazawa, Naoya Kukutsu, and Tomoaki Kumagai
ATR Wave Engineering Laboratories, 2-2-2 Hikaridai, Seika-cho, Soraku-gun, Kyoto 619-0288, Japan

***Abstract* – With the aim of achieving a wireless harness system in an automobile engine compartment (EC), radio propagation channels from 1.5 to 8 GHz in ECs were characterized with numerous measurements. Because there are many metal objects in EC, the channel's frequency-distance interdependence was taken into account in the characterization. As a result, the path loss exponents for distance were found to be about 1 and 3 below and above 450 mm, respectively. The exponent for frequency was 0.5 to 1. The delay spread increased as distance increased at a rate of about 3 ns/m. It also exhibited a decreasing trend with increasing frequency at the far distance.**

***Index Terms* — Propagation, automobile, path loss, delay spread**

I. INTRODUCTION

Wireless sensor networks are rapidly growing in many areas. One of the promising areas is automobile sensors. Many sensors are currently wired to the engine control unit. The benefits of making the connection wireless are reductions of material and assembly cost used for wiring, a weight reduction by the cable removal leading to a massive reduction of carbon footprint, etc. To design a wireless system, the propagation channel needs to be known. So far, propagation channels in the passenger compartment have been measured by several researchers, e.g. [1]. However, research on the propagation channels in engine compartments (ECs) are rarely found in the open literature.

In light of this, the authors carried out measurements at more than 40 locations in an EC. A preliminary characterization of the propagation channels and a data transmission were studied accordingly [2].

This paper presents more generalized and detailed discussion of propagation channels by measuring numerous additional channels, 210 in total, using multiple automobiles. Because there are many metal units, parts, pipes, etc., the sizes of which are comparable to the wavelength, channel dependence both on distance and frequency is taken into account.

II. MEASUREMENTS

Fig.1 outlines the measurement setup. The receiver (Rx), or the access point (AP), for all the sensor nodes was set closer to the passenger compartment and near the top of the EC. Meanwhile, the sensor node station (ST), or transmitter (Tx), was placed at more than 40 locations per automobile such that the straight-line distances between the Tx and Rx were as uniformly distributed as possible up to 1400 mm, including locations deep in the gaps between the parts and units. The automobiles we measured were Toyota Prius, Honda Insight, and Nissan Leaf. The antenna used for the Tx and Rx is a wideband monopole antenna shown within Fig. 1. The propagation channels were measured with a vector network analyzer from 1.5 to 8 GHz. The frequency step is 1 MHz which is small enough to capture virtually all the multipath components observed in the EC. In total, 210 propagation channels were measured.

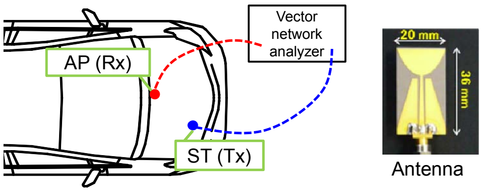


Fig. 1. Measurement setup

III. CHARACTERIZATION

A. Path loss

In ECs, there are many metal units, pipes, associated gaps, etc., sizes of which are comparable to the measured wavelength of 3.75-20 cm. Therefore, the diffraction and reflection will be frequency dependent, i.e. the channels can be presumably frequency dependent as well as distance dependent.

To include frequency-distance interdependence, the characterization method developed by the authors for ICT equipment [3] was applied. The path loss PL [dB] can be represented with frequency f and distance d as follows,

$$PL = 10(\eta_p \log_{10} f + \kappa_p)\log_{10} d + 10(\tau_p \log_{10} f + \xi_p) \quad (1)$$

where η_p, κ_p, τ_p, ξ_p are regression coefficients. The term $\eta_p\log_{10}f+\kappa_p$ is the path loss exponent for distance. One can rearrange (1) to obtain the path loss exponent for frequency, which is $\kappa_p\log_{10}d+\tau_p$.

The measured data sampled at 4 GHz are plotted in Fig. 2 as a function of distance. From this figure and the other data at different frequencies, there seems a break point at 450 mm. This suggests the locations above the break point tend to be deeply inside the EC, thereby having a larger path loss exponent. Hence, (1) is separately applied below and above the break point. The coefficients of (1) are extracted by applying least squares method with all the measured data.

Accordingly, (1) is plotted in Fig. 3. The additive error term for (1) was near normally distributed with the standard deviation of 7.2 dB for CW. As the bandwidth increases, the standard deviation decreases. The extracted path loss exponents for distance and frequency are plotted in Fig. 4 (a) and (b), respectively. The exponent for distance is about 1 and 3 below and above the break point, respectively. Only slight frequency-dependence is seen. The exponent for frequency is about 0.5 to 1. Not much difference was observed among automobiles.

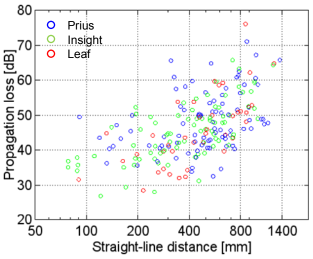


Fig. 2. Measured path loss at 4 GHz.

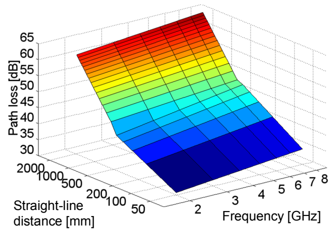
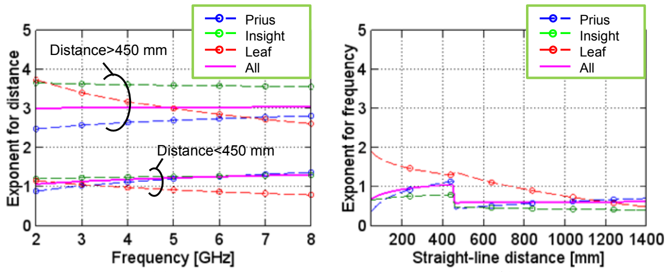


Fig. 3. Regression analysis result for path loss.



(a) (b)

Fig. 4. Path loss exponents for distance (a) and frequency (b).

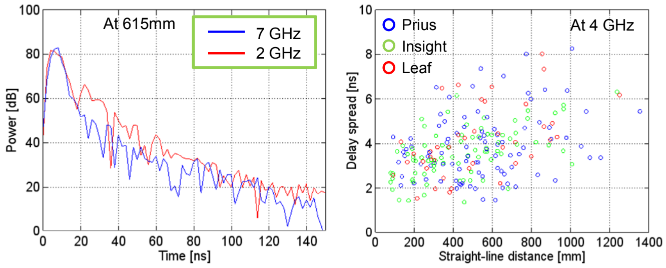
B. *Delay spread*

It is crucial to know the impulse response of the channel for designing a broadband system within a frequency selective fading environment. The power delay profile is evaluated with bandwidth of 500 MHz, which was chosen such that the bandwidth does not exceed 25 % at 2 GHz, i.e. the wavelength deviation was restricted to within ±1/8 λ while reasonably high resolution in time domain was retained. Fig. 5 (a) shows the power delay profile of the channel with ST location at 615 mm in Prius. The response exhibits quasi-exponential decrease in power as time increases. As can be seen, the profile depends on frequency.

Here, to obtain a basic insight into the channel characteristics, the delay spread was evaluated. The delay spread at 4 GHz is plotted in Fig. 5 (b). Again, there is no significant difference among the types of automobiles. To obtain the overall trend of delay spread as functions of distance and frequency, we assume the delay spread σ_τ [ns] as follows,

$$\sigma_\tau = (\eta_d f + \kappa_d) d + \tau_d f + \xi_d \qquad (2)$$

where η_d, κ_d, τ_d, ξ_d are regression coefficients. The model was arranged with an idea similar to (1). As a result of applying the least squares method, the coefficients were obtained and (2) was plotted in Fig. 6. The delay spread increases at a rate of about 3 ns/m. It also exhibits slightly declining tendency with increasing frequency at the far distance (-0.2 ns/GHz at 1400mm), which might be attributed to less multipath deep inside the EC due to larger diffraction or reflection loss at higher frequencies. The multiplicative error term for (2) was log-normally distributed with the standard deviation of $ln(1.36)$.



(a) (b)

Fig. 5. Measured delay profile (a) and delay spread (b).

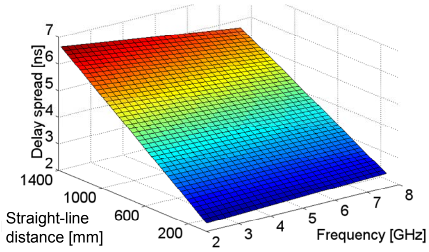


Fig. 6. Regression analysis result for delay spread.

IV. CONCLUSION

We measured and characterized numerous propagation channels in multiple automobile engine compartments. The path loss and delay spread are characterized with models having interdependence between distance and frequency taking into account the nature of the compartment. We plan to establish a delay profile model that can be applied to simulations of wireless sensor network systems.

ACKNOWLEDGMENT

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