Penetration loss of outer wall materials for co-existence of indoor and outdoor-use sensors at 79 GHz

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Abstract: This paper presents penetration loss measurements of housing outer wall materials at 79 GHz to investigate the co-existence between indoor-use and outdoor-use radar sensors. The penetration loss was measured for building outer wall materials such as window and concrete wall. The penetration loss is also compared with 24 GHz-band because the band is available as indoor-use (e.g., non-contacted health-care monitoring) and outdoor-use (e.g., automotive radar) sensor systems. The loss of indoor-to-outdoor systems is experimentally investigated. As a result, the propagation path through outer wall material, at a distance of 5 m from the house, is found to be approximately 50 dB attenuated, which is 15 dB larger as compared with 24 GHz.

Keywords: co-existence, 79 GHz, indoor sensor, automotive radar

Classification: Sensing

References

[1] M. Goppelt and H.-L. Blocher, “79 GHz automotive radar and its opportunities for frequency and bandwidth agile operation,” Proc. of 2017 International Radar Symposium, June 2017.

[2] K. Uchiyama, T. Motomura, and A. Kajiwara, “A study on self-vehicle location estimation employing 79 GHz UWB radar,” Proc. of 2018 IEEE Sensors Applications Symposium (SAS2018), Mar. 2018. DOI:10.1109/SAS.2018.8336785

[3] K. Oish, S. Okumura, T. Sakamoto, T. Sato, K. Mizutani, K. Inoue, T. Fukuda, and H. Sakai, “Non-contact interbeat interval measurement using higher harmonic components of body surface displacement with ultra-wideband Doppler radar,” IEICE Trans. Electron., vol. J101, no. 11, pp. 412–420, 2018.

[4] S. Matsuguma and A. Kajiwara, “Bathroom accident detection with 79 GHz-band millimeter wave sensor,” Proc. of 2019 IEEE Sensors Applications Symposium (SAS), Mar. 2019. DOI:10.1109/SAS.2019.8706084

[5] A. Morimatsu, S. Matsuguma, and A. Kajiwara, “Heart rate estimation of a moving person using 79 GHz-band UWB radar,” Proc. of 2019 IEEE Sensors Applications Symposium (SAS), Mar. 2019. DOI:10.1109/SAS.2019.8706073

[6] B. Kapilevich, M. Einat, A. Yahalom, M. Kanter, and B. Litvak, “Millimeter wave sensing behinds wall -feasibility study with FEL radiation-,” Proc. of FEL,
1 Introduction

24 GHz and 77 GHz frequency bands are currently assigned to automotive radar applications in Japan, and 79 GHz-band with up to 4 GHz bandwidth will become available soon. The 79 GHz-band automotive radar system is therefore on the market as a key technology for safety and self-driving systems because it offers all-weather capability, high range-resolution and wide-angle detection for peripheral monitoring [1, 2]. The 79 GHz-band has also attracted considerable attention as indoor-use applications such as non-contact vital (heart and respiration) monitoring because of the very high range-resolution and low privacy invasion [3, 4, 5]. To realize the co-existence with automotive applications for a same frequency band, however, the mutual interference must be understood accurately. Indoor to outdoor penetration loss is one of the most important factors of affecting the co-existence. Generally, the penetration loss at mm-wave frequencies is known to be larger relative to micro-wave frequencies, depending on the material types and incident angle [6, 7]. In this paper, penetration loss of housing outer wall materials such as window and concrete walls was measured to discuss the mutual interference at 79 GHz. Especially, outer wall windows will be crucial since the penetration loss should be lower than other wall materials. The penetration loss is also compared with 24 GHz because the 24 GHz band is available as indoor-use (e.g., security and industry robot sensor) and outdoor-use (e.g., automotive and unmanned aerial vehicle radar) sensor systems. As a result, the 79 GHz signal is found to be largely attenuated by glass window walls.

2 Measurement set-up and wall penetration loss

A. Measurement setup and penetration loss

Measurement was conducted in a frequency range of 79–80 GHz using a VNA (Agilent: E8363B) with millimeter modules in an anechoic chamber room. The measurement was also conducted in a range of 24–25 GHz for comparative study of penetration loss. Housing outer walls are generally made of concrete, PB (plaster-board), glass window walls. Especially, modern residential window wall includes double-paned glass and coated glass with a thin UV-cut seal to improve indoor comfort in summer and to prevent indoor thermal loss in winter. The former may have a frequency selective penetration loss depending on the air-space thickness, while the latter some insertion loss. Frosted window glass is also used widely which allows visual privacy, while still allowing penetration of natural light. We therefore consider (i) clear window glass of 5 mm thick, (ii) frosted window glass of 5 mm thick, (iii) UV-cut window glass of 6.6 mm thick, (iv) double-paned window glass of 13.8 mm thick, (v) PB wall of 70 mm thick, and (vi) concrete wall of 80 mm thick as illustrated in Fig. 1(a). The transmit and receive antennas with a gain
20 dBi were always boresight-aligned with the material on turn table placed in between both the antennas as shown in Fig. 1(b).

Penetration loss was calculated as the difference with the received power, $P_{FS}$, in free space with the same Tx-Rx separation distance. The penetration loss $L$ is given by,

$$L = [P_{FS}] - [P_m]$$

$$P_{FS} = [P_t] + [G_t] + [G_r] + 20 \log_{10} \left( \frac{c}{4\pi df} \right)$$

where $P_t$ is the transmit power, $G_t$ and $G_r$ are the transmit and receive antenna gain respectively, $c$ is the speed of light, $f$ is the frequency, and $P_m$ is the received power for a material.

B. Measurement result

The measurement of each material was conducted as a function of incidence angle. Measurement results of a single clear and frosted glass are shown in Fig. 2(a) and (b) respectively. The penetration loss of clear glass for low incident angle is not almost seen at 24 GHz, while approximately 3 dB at 79 GHz. And increased penetration losses have been observed for larger incident angle. For the frosted glass, the effect of surface roughness on loss is not seen for the incident angle of less than 30°. This is because the surface roughness is much less than the wavelength. Measurement results for laminated and double-paned window glass are shown in Fig. 2(c) and (d) respectively. Some insertion loss of metallic seal is seen for 24 GHz, but small for 79 GHz. The penetration loss of double-paned window glass at 79 GHz is approximately 14 dB and is like to decrease with the incident angle unlike 24 GHz. As predicted, therefore, the doubled-paned glass is seen to have some frequency selective penetration loss for 79 GHz because of the resonance. Please note that the air space between window panes is approximately half.
of the wavelength of 79 GHz. The penetration loss for PB wall (plaster-board plus insulating material) and concrete wall are shown in Fig. 2(e) and (f) respectively. The penetration loss of the PB wall is relatively small which is similar to the single window glass. And the loss for the concrete for 79 GHz is 80–100 dB which is double of 24 GHz. It is found from the above results that the penetration loss of 79 GHz is large relative to 24 GHz.

### 3 Propagation loss

Interference from an indoor-use sensor at 79 GHz to outdoor-use sensor is investigated where the measurement was conducted in a house (3LDK, 91 m$^2$). The Tx antenna with a height of 0.6 m was placed 1.5 m away on the inside from the window glass wall and the outside received powers were recorded at a total of 196 locations for an area of 5 × 5 m$^2$ as shown in Fig. 3. The thickness of exterior concrete wall is 250 mm and the window wall is double-paned window glass with

![Fig. 2. Penetration loss of housing outer wall materials for 24 and 79 GHz](image-url)
of 13.8 mm-thin. Fig. 3(a) and (b) show the top-viewed received power distribution through outer walls at 79 GHz and 24 GHz respectively, where the transmit power is 0 dBm and the Tx and Rx antenna height is 60 cm. The window glass leakage is approximately 20–30 dB at 79 GHz, while 40–50 dB at 24 GHz. And the sensor radio isolation at 79 GHz is seen to be high because of the high penetration loss and
diffraction loss. Another loss factor is the path attenuation of the signal as a function of two material space. It is interesting to investigate the path loss coefficient for line-of-sight area through the outer walls because it is a major component in the design of the link budget or interference effect. The coefficient for 79 GHz and 24 GHz are approximately 2.12 and 1.61 respectively. And the propagation path through outer wall material at 79 GHz is found to be approximately 50 dB attenuated at a distance of 5 m from the house, which are 15 dB larger as compared with 24 GHz. Suppose an acceptable interference level of 70 dBm, for example, the probability that the mutual interference will occur is low when the outdoor-use system is 30 m away from the house.

4 Conclusion

In this paper, we conducted the measurement of indoor-to-outdoor attenuation of 79 GHz-band sensor signal where some concrete wall and several types of window wall are considered. And the penetration loss was also compared with 24 GHz-band. The interference level of indoor-to-outdoor sensor systems at 79 GHz is shown to be significantly attenuated by outer walls and window glasses. As a result, the effect of indoor-use sensor on vehicular radar system is found to be relatively small at 79 GHz and the probability that mutual interference will occur is low.