

# Effect of Reflected Waves from Outdoor Buildings on Outdoor-to-Indoor Path Loss in 0.8 to 37 GHz Band

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**Abstract** –The measurement results of outdoor-to-indoor path loss characteristics in multiple frequency bands from microwave to millimeter wave are described. We clarified that the path loss characteristics dependence on frequency. Moreover, ray tracing is used to analyze the propagation phenomena causing frequency dependence. A comparison between measured and calculated results clarified the dominant paths that is multiple reflected at an outdoor building and then diffracted into building. These results show that the value of the root mean square error is about from 4 dB to 8 dB in 0.8 to 37 GHz band. We confirm that these paths are dominant and affect the frequency dependence of outdoor-to-indoor path loss.

**Index Terms** — Outdoor-to-indoor path loss characteristics, frequency characteristics, small cell

## 1. Introduction

The traffic in wireless communication systems has been rapidly increasing in recent years and is assumed to reach 1000 times higher than the current traffic amount in the next 10 years. Since microwave bands below 6 GHz are used extensively in such systems, their frequency resources are very tight. One of the ways being examined to solve these problems is applying frequency bands above 6 GHz to the next generation (5G) mobile communication systems. These frequency bands include the millimeter-wave bands that can use wider frequency bandwidth and provide attractive higher throughput. Using a new frequency band requires an understanding of the path loss characteristics dependence on frequency in order to evaluate the transmission characteristics. Furthermore, it is assumed that the main service areas of 5G using high frequency bands above 6 GHz will be environments such as InH (Indoor Hotspot) and outdoor UMi (Urban Microcell) environments [1]. So far, the path loss characteristics at high frequency bands in UMi environment have been reported [2]. However, in developing small cells it is necessary to evaluate the interference between mobile terminals and the coverage area inside buildings. Nevertheless, no method of clarifying the outdoor-to-indoor path loss of high frequency bands has yet been clarified [3] [4].

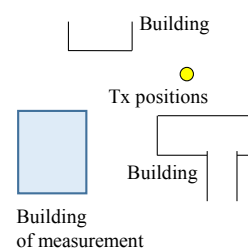
Therefore, this paper describes outdoor-to-indoor path loss characteristics and frequency characteristics on the basis of measurement results in multiple frequency bands, including high frequency bands above 6 GHz. We also use ray tracing to clarify the dominant paths on the basis of comparison between analysis and measurement results.

## 2. Measurement parameters and environment

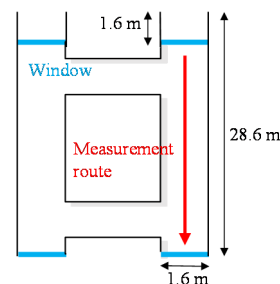
The path loss measurements were taken in the environment shown in Fig. 1. Table 1 summarizes the measurement parameters. The measurements were taken in six frequency bands for 0.8, 2.2, 4.7, 8.4, 26 and 37 GHz in order to ascertain the frequency dependence. The transmitter (Tx) antenna was fixed on the roof of a measurement car 2.5 m in height. The car was parked on the roadside at A-1 in Fig. 1 (a). The position A-1 was regarded as a line-of-sight (LOS) environment. A receiver (Rx) antenna was fixed on the Rx units of a hand truck. Measurements were taken at the 8th floor of the building. The Rx antenna height was 1.5 m above the floor and the floor height was 3 m. Both the Tx and Rx antenna radiation pattern were omnidirectional.

Table I: Measurement parameters

|                             |                                |
|-----------------------------|--------------------------------|
| Frequency (GHz)             | 0.8, 2.2, 4.7, 8.4, 26.3, 37.0 |
| Tx antenna height (m)       | 2.5                            |
| Rx antenna height (m)       | 1.5 (above the floor)          |
| Floor number of measurement | 8F                             |
| Antenna radiation pattern   | Omni-directional               |



(a) Outdoor building layout



(b) Indoor environment of building  
Fig. 1. Measurement environment.

### 3. Outdoor-to-indoor path loss measurement and analysis results for 0.8 to 37 GHz bands

#### (1) Measurement results

Figure 2 shows the results we obtained in measuring the frequency characteristics of path loss in the 0.8 to 37 GHz bands. To evaluate the frequency characteristics, the outdoor-to-indoor path loss  $PL_{norm}$  is normalized by subtracting the outdoor free space loss from the measured path loss  $PL_{meas}$  by using the following formula.  $d_{out}$  is distance from Tx to the wall next to Rx.  $d_{in}$  is perpendicular distance from a wall to Rx.

$$PL_{norm} = PL_{meas} - 20 \log_{10}(4\pi(d_{out} + d_{in})/\lambda) \quad (1)$$

The y-axis in Fig. 2 is the normalized path loss and the x-axis is the moving distance. At 2.5 m distance, the path loss at 0.8 GHz frequency was found to be about 15 dB but 30 dB at 37 GHz. This clearly indicates that the outdoor-to-indoor path loss increases substantially as the frequency increases. Therefore, we assume that the path loss depends on the frequency because it affects the diffracted waves from the nearest window to the Rx.

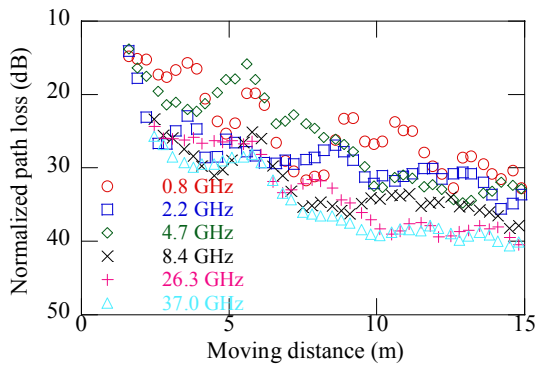


Fig. 2. Frequency characteristics of path loss

#### (2) Analysis results by using ray-tracing

Furthermore, to analyze the frequency characteristics of the path loss, we calculated by using ray-tracing with a simulation model including only the building of measurement (Fig. 3 (a)). From Fig. 2, the measurement results confirmed the path loss is dependent on frequency. Because the diffracted waves that varied with frequency would be affected, we took the diffracted path into consideration. The Tx position, antenna height, and antenna radiation pattern were to the same as those in the measurement. The Rx antennas were placed 0.1 m apart in a corridor of the building. The wall was set to be a concrete wall with a 6.76 dielectric and 0.0023 conductivity. Figure 4 compares the calculation and measurement results. In this comparison, the calculated path loss values with model (A) were larger than the measured ones. The root mean square error (RMSE) value between the calculated and measurement results was about 34.8 dB at 0.8 GHz, 40.3 dB at 2.2 GHz, 40.3 dB at 4.7 GHz, 45.1 dB at 8.4 GHz, 42.7 dB at 26 GHz and 42.1 dB at 37 GHz, respectively. We assumed that the reason for this gap was that other outdoor buildings are not modeled. Thereby, the dominant reflected paths from them were not taken into consideration. Therefore, we also calculated the path loss while taking the dominant reflected paths from other buildings into consideration. Figure 3 (b) shows the simulation model including the building of measurement and other outdoor buildings. From Fig. 4, frequency characteristics calculated with model (B) were closed to the measured ones. The RMSE value between calculation and measurement results was about 5.7 dB at 0.8

GHz, 4.9 dB at 2.2 GHz, 8.3 dB at 4.7 GHz, 4.2 dB at 8.4 GHz, 3.8 dB at 26 GHz and 4.3 dB at 37 GHz, respectively. These results clarify the paths that is reflected multiple times at an outdoor buildings and then diffracted into building are dominant. We found that it affects the frequency characteristics of outdoor-to-indoor path loss.

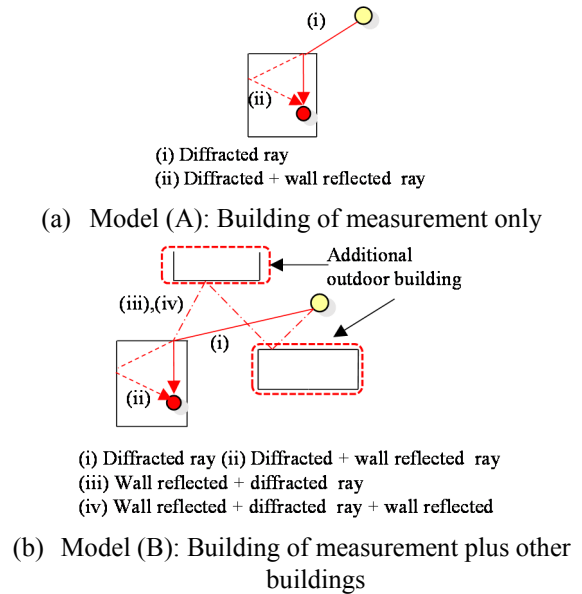


Fig. 3. Simulation models.

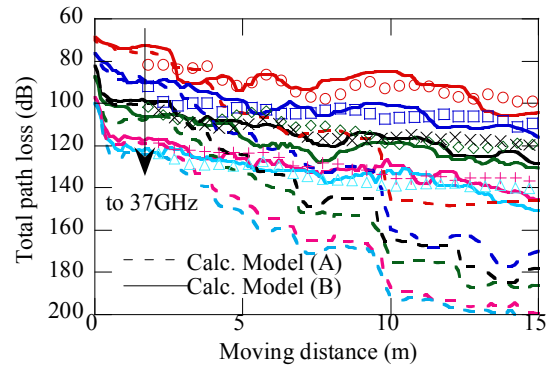


Fig. 4. Comparison of calculation and measurement results.

### 4. Conclusion

We evaluated the frequency characteristics of the outdoor-to-indoor path loss in 0.8 to 37 GHz bands. In addition, we used ray tracing to analyze the propagation phenomena causing the dependence. From the comparison of measurement and calculated results, we found that the paths that multiple reflected at an outdoor building and then diffracted into building are dominant. These results showed that the RMSE value was about from 4 dB to 8 dB in 0.8 to 37 GHz band. We concluded that those paths are dominant and affect the path loss dependence on frequency.

### References

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