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Path Loss Characteristics between Different Floors from 0.8 to 37 GHz in Indoor Office Environments

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***Abstract* - This paper describes analytical results obtained for floor penetration loss characteristics and their frequency dependency by measuring in multiple frequency bands, including those above 6 GHz, in an indoor office environment. Measurement and analysis results show that the floor penetration loss depends on two dominant components: paths through floors and outside buildings. It was clarified that the characteristics of these paths determine the frequency dependency of the floor penetration loss.**

Index Terms — Propagation, 5G, millimeter wave, high frequency bands, indoor office, floor penetration loss.

1. Introduction

In order to develop fifth-generation mobile communication systems (5G), various organizations have studied the use of frequency bands above 6 GHz [1-3]. These studies were done under the assumption that indoor environments such as an office would be typical scenario for applying high frequency bands. The channel characteristics of a single floor have been studied to figure out the coverage area. The path loss characteristics between different floors are also important to manage the interference, which was shown as floor penetration loss in [4][5]. However, in these studies the frequency range was limited to the bands below 6 GHz. Therefore, this paper reports the floor penetration loss characteristics and their frequency dependency obtained by taking measurements in multiple frequency bands.

2. Measurement Method and Parameters

Fig. 1 shows the measurement environment and Table 1 summarizes the measurement parameters. The measurements were carried out from the 3rd to the 6th floor of a large office (50 m width × 16 m depth × 2.7 m above-floor height). The office windows are on the right side and at the bottom of the figure. Each floor had the same layout. Transmitter (Tx) antennas were placed in two locations (Tx1 and Tx2) on the 6th floor. Tx1 was set near the center of the room and Tx2 was placed near the edge of the room as shown in Fig. 1. The height of the Tx antennas was 2.6 m above the floor. Receiver (Rx) antennas with height of 1.5 m above the floor were set on a push car. We measured the received power by moving the push car as shown by the red line in Fig. 1. From the 3rd to the 5th floor, the Rx routes were the same as that on the 6th floor. On the 6th floor, all measurement points were line-of-sight (LoS) from Tx because the appliances were no more than about 1 m in height. In order to obtain the frequency dependency, five measurement frequencies were used, including high frequency bands above 6 GHz (0.8, 2.2, 4.7, 26.4, and 37.1 GHz). A continuous wave was used at all five frequencies. We obtained the path loss by subtracting gains and losses of the measurement setup after calibration. To exclude the effects of fast fading, median values were obtained at 1-meter intervals.

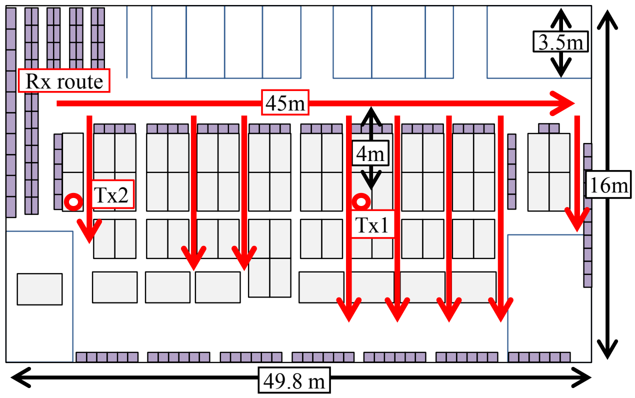

Fig. 1. Measurement environment.
(Same layout in floors 3-6; Txs only on 6th floor.)

TABLE I
Measurement parameters.

Frequency (GHz)	0.8, 2.2, 4.7, 26.4, 37.1
Tx / Rx antenna height (m)	2.6 / 1.5 (above the floor)
Tx / Rx antenna half power beam width	H-plane: Omni-directional V-plane: 60 degrees

3. Analysis of Path Loss Characteristics

Fig. 2 shows the measurement results using Tx2 at the longest Rx route of 45 m, on the 5th floor. As can be seen, the measured path loss at 0.8, 2.2, and 4.7 GHz attenuates more than 10 dB with increasing Tx-Rx distance. This indicates a direct path through floors exists and is dominant at these frequencies. On the other hand, despite the increase in Tx-Rx direct distance, the measured path loss at 26 and 37 GHz varies little over the measurement route. We assumed that this is due to the path diffracted at edges of the windows and through outside the building. Therefore, we show the propagation model of the dominant paths between different floors in Fig. 3. As the figure shows, there are two dominant paths; one is the transmission path through floors, and the other is the path through the outside building.

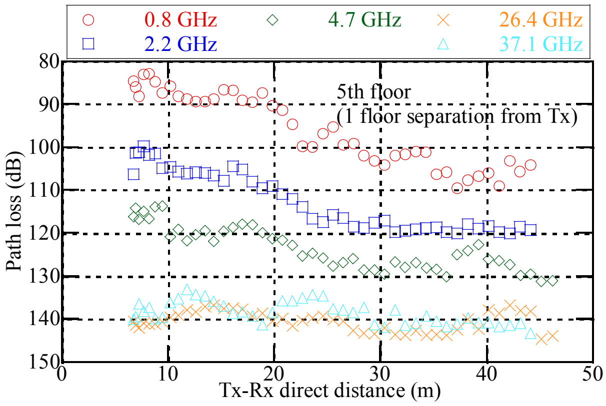

Fig. 2. Measurement results on 5th floor (Tx2).

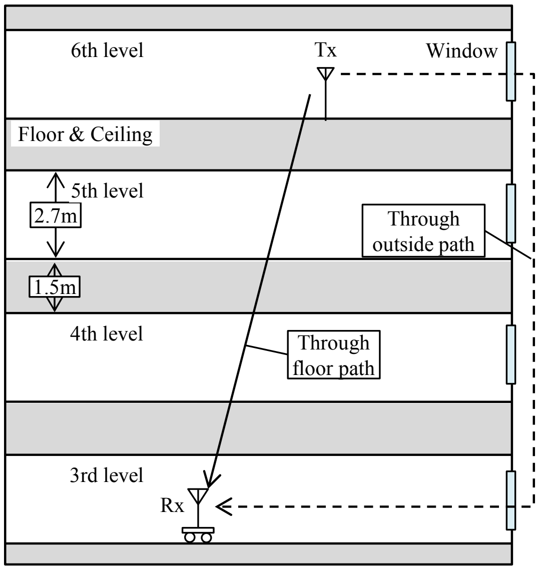

Fig. 3. Dominant paths between different floors.

Fig. 4 calculates the frequency dependency of these two dominant paths' losses. The transmission losses represent the path through floors, which were calculated using a single-layer slab made of concrete with thickness w (1.5 m for each floor) [6]. The diffraction losses represent the path through the outside building diffracted at windows, which were calculated using an absorbing wedge with an incident angle of 90 degrees [5]. As the figure shows, the transmission loss rapidly increases with higher frequency and material thickness. On the other hand, with increasing frequency the diffraction loss increases rather more gradually than the transmission loss.

Finally, we analyzed the measured loss on the basis of the two paths' characteristics. Fig. 5 represents the floor penetration loss of five frequencies at each floor. These losses were derived by calculating the median value of all measurement points each floor (including both Tx1 and Tx2), and subtracting the median value of the 6th floor from the values at each floor. At the 4th and 3rd floors, the loss increases linearly over all frequencies. On the other hand, at the 5th floor, the floor penetration loss from 0.8 GHz to 4.7 GHz increases more than that from 4.7 GHz to 37 GHz. This is because when lower frequency is used and the floor separation becomes low, the through floor path is dominant and so its frequency dependency is larger. However, when higher frequency is used or the floor separation becomes large, the diffracted path through the outside building becomes dominant. Therefore, these results show that the two dominant paths and their loss characteristics should be taken into account for channel modeling of the floor penetration loss characteristics. In particular, it causes frequency dependency over a wide frequency range including high frequency bands above 6 GHz.

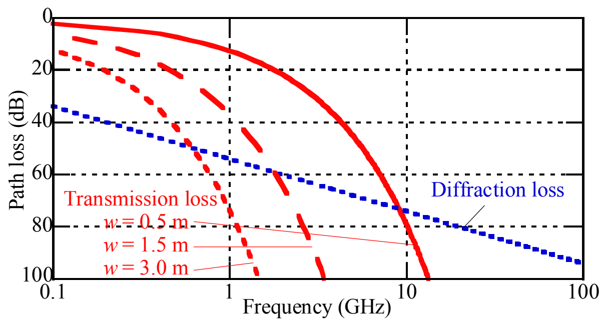

Fig. 4. Transmission and diffraction loss characteristics.

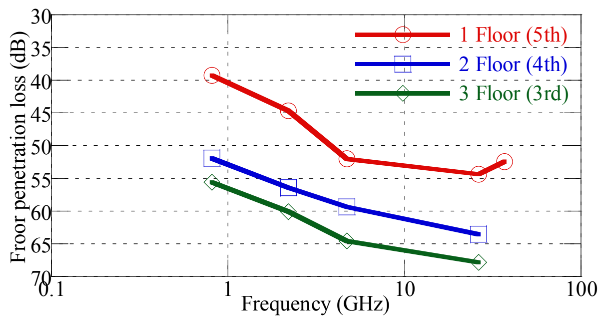

Fig. 5. Floor penetration loss (Tx1 and Tx2).

4. Conclusion

Path loss between different floors in an indoor office environment was measured for various frequency bands between 0.8 and 37 GHz. On the basis of analysis of measurement results, we clarified that that the floor penetration loss characteristics depend on the two dominant paths and their frequency dependency.

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