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Multi-frequency Measurements of Material and Floor Penetration Losses

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Abstract

In light of the present and future 5G and 6G multi-band communications, achieving seamless indoor wireless coverage appears to be an important challenge. Within this context, continuous wave measurements were conducted in this work to estimate floor-penetration loss in the FR3 band (7-15 GHz) and the penetration loss of other indoor structures, such as walls and doors, at 25, 77 and 153 GHz. In the FR3 band, through-floor losses varied between 44 and 64 dB for frequencies from 7 GHz to 15 GHz, with an increase of about 18-20 dB for each of the considered cases. Similarly, other losses increase with frequency by 22 dB (glass door) and by 33 dB (indoor partition walls) across the three measured frequency bands.

1 Introduction

Indoor communications are of particular interest since the majority of the data traffic nowadays is generated within indoor environments [1]. The introduction of higher frequency bands for various applications in the wireless communication field poses challenges to indoor propagation, especially at mm-wave and sub-THz frequencies where walls, doors, and floors are recognized to heavily hinder the propagation. The strong attenuation due to indoor structures is undesirable when seamless indoor coverage is the primary goal, yet it can have a positive outcome when interference suppression is the main interest.

In order to comprehensively study the signal propagation indoor, an evaluation of how different frequencies interact with various indoor structures should be made [2] [3]. Among common indoor structures, walls and doors play crucial roles. A characterization of frequency-dependent losses exhibited by these structures is fundamental for effective coverage planning. Various measurement campaigns have been reported in the literature regarding the wall and door penetration losses: in [2] for 28 and 140 GHz, in [4] for 73 and 81 GHz, in [5] for 28 and 72 GHz. Nonetheless, a noticeable gap remains in the literature regarding comprehensive studies that consider penetration losses of indoor structures across a wide frequency spectrum encompassing mm-waves to sub-THz frequencies.

Another key mechanism of indoor propagation that is scarcely investigated is the floor penetration loss that heavily depends on the operating frequency and the type of floor under consideration. Notably, the only existing studies belong to low frequency bands as in [6] for 2.4 GHz and [7] for 2.4 and 5.8 GHz. The lack of floor penetration loss knowledge above 5.8 GHz is reflected in the gap in standardisation models such as the ITU-R P.1238-12 recommendation [8], where mean values of floor penetration loss calculated across various buildings are only provided up to 5.8 GHz. Moreover, despite the ongoing research focus on mm-waves and sub-THz frequencies, also the mid-band within 7-24 GHz (known as FR3 band) has gained importance as it has emerged as a possible candidate for early 6G applications. Consequently, a characterisation of floor penetration loss within the FR3 band becomes of great importance, thus contributing to international standards.

Therefore, this work addresses the aforementioned gaps in the literature by conducting a measurement campaign to analyze the penetration loss of indoor structures at 25, 77 and 153 GHz and a measurement campaign focused on characterizing floor penetration losses in the FR3 band, specifically within the frequency range from 7.5 to 14.5 GHz.

2 Measurement Campaigns

The measurements were conducted in the Department of Engineering at Durham University, UK, built in the 1980s and reconstructed in the 2010s using two different setups as outlined below.

2.1 Floor measurements setup

As for floor penetration measurements, three different environments with different floor type inside the Department of Engineering were chosen as can be seen from Figure 1. The first environment is the floor of an office area with a thickness of 58 cm where apart from the floor thickness, a 20 cm empty lowered ceiling is present. The second environment is the hall close to stairs with a thickness of 26 cm, while the last environment corresponds to a workshop area with a thickness of 50 cm. Both antennas were installed on tripods designed for measurements and were perfectly aligned vertically on both floors as seen from the schematic representation in Figure 2a. The floor penetration losses were measured using a continuous wave (CW) Gigatronics function generator at the transmitter side and a high-

Scenario	Office area			Hall Stairs area			Workshop area		
Frequency	*Mean loss [dB]*	*Std. [dB]*	*Spec.loss [dB/cm]*	*Mean loss [dB]*	*Std. [dB]*	*Spec.loss [dB/cm]*	*Mean loss [dB]*	*Std. [dB]*	*Spec.loss [dB/cm]*
7.5	44.31	0.223	0.76	40.37	0.161	1.55	44.73	0.785	0.89
8	46.96	0.301	0.81	42.89	0.352	1.65	48.47	0.943	0.97
9	48.97	0.566	0.84	45.92	0.429	1.77	50.15	0.733	1
10.5	53.33	0.343	0.92	47.43	0.332	1.82	54.48	1.152	1.09
12	56.22	0.542	0.97	52.71	0.507	2.03	57.65	1.222	1.15
13	60.88	0.537	1.05	56.21	0.577	2.16	62.20	0.695	1.24
14.5	63.89	0.227	1.1	58.57	0.415	2.25	64.50	0.942	1.29

Table 1. Floor penetration losses at different environments

end Keysight spectrum analyser at the receiver side. The transmit power was 15 dBm. Wideband antennas were used for the measurements with the frequency varying from 7.5 to 14.5 GHz : log-periodic antennas were used from 7.5 GHz up to 9 GHz and horn antennas from 10.5 GHz up to 14.5 GHz. The gain of the log-periodic and horn antennas were 6 dBi and 20 dBi respectively. Cable losses of this setup are equal to 6 dB. The floor penetration loss was estimated as the difference between the measured received power and the free space received power, computed through the Friis equation. Generally, floors can be heterogeneous due to construction or pipes passing through them. In order to have a representative figure of the whole floor attenuation, for each environment measurements were repeated 3 times by changing simultaneously the transmitter and receiver along a 1 meter straight line. Furthermore, at each location 8 samples of measurements were recorded, minimizing in this way random fluctuations due to the environment. The mean value and the standard deviation of the floor penetration loss for each environment and for each frequency was then calculated.

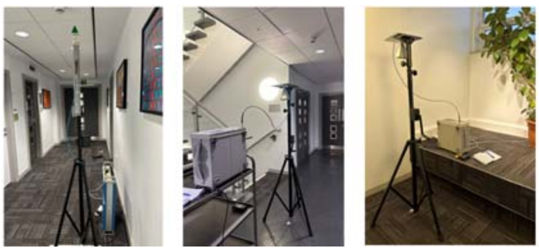
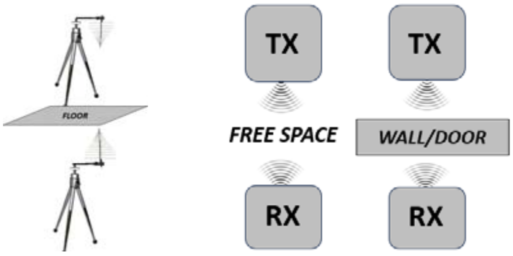


Figure 1. Measurement environment: Hall office area (first), Hall workshop area (second), Hall stairs area (third)



(a) Through floor

(b) Wall/door

Figure 2. Schematic setup of measurement campaigns

2.2 Walls and doors measurements setup

In order to study the impact of indoor structures on signal propagation, a 1.27 cm glass door, a 4.4 cm wooden door, a 16 cm main partition wall between two offices (labelled as wall partition 1) and a 26 cm partitioning wall between two halls (labelled as wall partition 2) were considered as seen from Figure 3. In the measurements for the wall penetration loss a custom designed measurement setup to study the impact of precipitation at Durham University was used. The setup uses a programmable phase locked loop (PLL) to generate a CW signal at an intermediate frequency which is then multiplied by 2, 6 and 12 to generate the frequencies at 25.6 GHz, 77 GHz and 153 GHz, respectively. At the receiver side, a similar PLL but with a frequency offset is used to mix with the incoming signals in order to generate a low frequency beat note at 4 MHz, 12 MHz and 24 MHz respectively. For the present measurements the transmitter and receiver units were set up facing each other, at the same height, and the received signal from the three bands was measured on the Keysight spectrum analyser first without the doors/walls (free space) and then with the walls/doors between the Tx and the Rx, as shown in Figure 2b. To minimize the measurement error, 4 measurements were recorded for each scenario and the mean value was used to estimate the difference between wall/door and free space.

Figure 3. Setup of measurements: Glass door (first), Wooden door (second), Wall partition 1 (third), Wall partition 2 (fourth)

3 Results and discussions

3.1 Floor penetration loss results

Table 1 summarises the results of the evaluated losses as described in Section II.A. It can be noticed that the penetration losses of the "Office area" and the "Workshop area" are quite similar, even though the specific attenuation (evaluated as the mean floor loss divided by the thickness of the

Frequency [GHz]	Glass door		Wooden door		Indoor partition wall (1)		Indoor partition wall (2)	
	Mean loss [dB]	*Specific loss [dB/cm]*	*Mean loss [dB]*	*Specific loss [dB/cm]*	*Mean loss [dB]*	*Specific loss [dB/cm]*	*Mean loss [dB]*	*Specific loss [dB/cm]*
25	4.12	3.24	10.17	2.31	17.39	1.08	26.64	1.02
77	14.08	11.08	21.21	4.82	27.53	1.72	38.40	1.48
153	26.28	20.69	41.97	9.54	53.63	3.35	59.17	2.28

Table 2. Mean penetration and specific attenuation through walls/doors

floor in cm) is slightly higher for the "Workshop area". As seen from Table 1, through-floor losses vary between 44 and 64 dB for the "Office area" and the "Workshop area", for frequencies ranging from 7.5 GHz to 14.5 GHz, while the "Hall Stairs area" exhibits slightly lower losses across all frequencies (from 40 to 58 dB). However, the highest specific attenuation value (1.55 dB/cm at 7.5 GHz and 2.25 dB/cm at 14.5 GHz) is found in the "Hall Stairs area" and this is in agreement with the fact that the stairs are the most solid structure in a building, thus, exhibiting a higher attenuation. In all cases a constant increase of the mean attenuation value with frequency increase is observed (2-3 dB for each 1 GHz increase in frequency). Considering this current trend in mean floor attenuation values, it indicates that in the building under consideration, it is not possible for the signal to propagate through two floors nor for the signal to propagate at mm-wave frequencies, as the value of the corresponding loss would be too high. Furthermore, as it can be seen from Figure 4 (different points for one single frequency value) for the "Workshop area" where a 1m scan is performed, the different values for each frequency highlight the presence of small variations in the floor structure. This observation is furthered confirmed by the second location (red dots) which always shows the highest attenuation value while the third location (ciano stars) exhibits the smallest attenuation. However, as frequency approaches 12 GHz, these differences become less evident. For this reason, to account for possible floor unevenness it is advised to take measurement samples in several different locations within the considered environment.

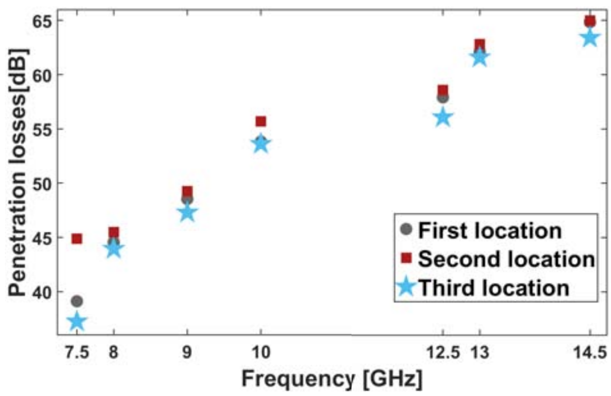


Figure 4. Scanning of Hall Workshop area floor along 3 different locations

3.2 Indoor partition losses

The results of the losses across the walls and the doors are summarised in Table 2 for the glass door, the wooden door and two partition walls, with wall 1 being the wall between two offices and wall 2 being the wall between two halls. The glass door exhibits smaller mean losses compared to the wooden door and the difference between the two becomes more significant as the frequency increases from 77 to 153 GHz. Yet, the specific attenuation (see Section III.A. for definition) of the glass door is significantly higher than the wooden door. When considering the partition walls, the specific attenuation shows similar values. This characteristic explains the smaller mean loss value of wall 1 which, being thinner than wall 2, exhibits, on average, 8 dB smaller loss than wall 2. Partition wall 1 has a penetration loss of 17.39 dB at 25 GHz which is in good agreement with other measurements such as in [9].

4 Concluding remarks

In this study two continuous wave (CW) measurements were carried out aimed at assessing floor penetration loss within the frequency range of 7-15 GHz (FR3 band) and penetration loss through indoor structures at 25, 77, and 153 GHz. Within the FR3 band, losses through floors ranged from 44 to 64 dB across frequencies from 7 GHz to 15 GHz, exhibiting an increase of approximately 18-20 dB for each considered case. The findings in the considered buildings indicate that signal propagation across two floors at millimeter-wave frequencies is impractical, primarily attributed to the significantly high losses. Similarly, indoor partition loss showed a frequency-dependent rise of 22 dB for glass doors and 33 dB for indoor partition walls across the three measured frequency bands. These outcomes underscore the challenge of attaining uninterrupted wireless coverage within indoor spaces, especially at mm-wave frequencies.

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References

[1] Z. Li, H. Hu, J. Zhang, and J. Zhang, "Impact of wall penetration loss on indoor wireless networks," *IEEE Antennas and Wireless Propagation Letters*, vol. 20, no. 10, pp. 1888–1892, 2021.

[2] B.-E. Olsson, C. Larsson, M. N. Johansson, and S. L. H. Nguyen, "Radio propagation in an office environment at 140 ghz and 28 ghz," in *2021 15th European Conference on Antennas and Propagation (EuCAP)*, 2021, pp. 1–5.

[3] Y. C. Lee, S.-S. Oh, C. W. Byeon, K. Aziding, and B.-L. Cho, "Impact of window penetration loss on building entry loss from 3.5 to 24 ghz," *IEEE Access*, vol. 9, pp. 138 571–138 579, 2021.

[4] M. Khatun, C. Guo, D. Matolak, and H. Mehrpouyan, "Indoor and outdoor penetration loss measurements at 73 and 81 ghz," in *2019 IEEE Global Communications Conference (GLOBECOM)*, 2019, pp. 1–5.

[5] G. Barb, F. Danuti, M. A. Ouamri, and M. Otesteanu, "Analysis of vegetation and penetration losses in 5g mmwave communication systems," in *2022 International Symposium on Electronics and Telecommunications (ISETC)*, 2022, pp. 1–5.

[6] S. M. Yee Aung and M. M. Maw, "Analysis of indoor channel propagation characteristics in multi-floored building at 2.4 ghz," in *2017 21st International Computer Science and Engineering Conference (ICSEC)*, 2017, pp. 1–5.

[7] S. Y. Lim, Z. Yun, and M. F. Iskander, "Radio propagation measurements in multifloor indoor stairwells," in *2010 IEEE International Conference on Wireless Information Technology and Systems*, 2010, pp. 1–4.

[8] I. T. U. ITU-R, Rec. ITU-R P.1238-12, "Propagation data and prediction methods for the planning of indoor radiocommunication systems and radio local area networks in the frequency range 300 mhz to 450 ghz," August. 2023.

[9] V. D.-E. M. Buccioli, E. M. Vitucci, "Analysis of mm-wave scattering from construction materials," in *Proceedings of the XXXIVth URSI General Assembly and Scientific Symposium (URSI GASS 2021)*, 2021, pp. 1–4.