Characteristics Analysis of Reflection and Transmission According to Building Materials in the Millimeter Wave Band

Byeong-Gon Choi, Won-Ho Jeong, Kyung-Seok Kim

***Abstract*—**Millimeter wave is the propagation of short wavelength and wide bandwidth. Since the advantages of the millimeter wave band include miniaturization, weight reduction of components and a lot of information transfer, it has become an alternative frequency band for next-generation mobile communications. Also, it is strongly affected by climate and geographic features. So, characteristics analysis of reflection and transmission is required to use the millimeter wave band effectively. In this paper, we measure and analyze reflection and transmission characteristics according to various building materials from 13GHz to 28GHz in the millimeter wave band. For reflection measurement, we measured received power reflected from materials with changing incidence and reflection angles. For transmission measurement, we measured received power penetrating materials with changing reception angle. From these measurement results, we analyzed reflection and transmission characteristics according to building material and change of angle from 13GHz to 28GHz in the millimeter wave band.

***Keywords*—**Reflection, Transmission, Millimeter wave, Building materials.

I. Introduction

THE millimeter wave band has a frequency range of 30 to 300GHz and a 1 to 10mm wavelength. Because of the difficulty in controlling it and the disadvantages of transmission loss, the utilization of millimeter waves has been low. However, since the advantages of the millimeter wave band include miniaturization, weight reduction in components, and a lot of information transfer, it has become an alternative frequency band for next-generation mobile communications. Also, the use of smart devices such as the smartphone and tablet PCs has exploded, so high-speed, broadband and high-definition communications has been required. As a result, the need for research into millimeter waves has been increasing [1], [2]. In particular, one essential research area on millimeter waves is characteristics analysis of reflection and transmission because it is strongly affected by climate and geographic features [1], [3].

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In this paper, we measure and analyze reflection and transmission characteristics according to various building materials from 13GHz to 28GHz in the millimeter wave band by using a signal generator, a spectrum analyzer and directional antennas. Also, we measure and analyze reflection and transmission characteristics according to change of angle by changing incidence and reflection angles in each reflection measurement and reception angle in transmission measurement. In each measurement, we measure received power and loss of reflection and transmission with comparison to a reference material. Then, we derive reflectance and transmittance according to the material and change of angle. From these results, we confirm reflection and transmission characteristics according to material and change of angle from 13GHz to 28GHz in the millimeter wave band.

This paper is organized as follows. Section II discusses reflection and transmission systems and the measurement procedure. Reflection measurement results are shown in Section III, and transmission measurement results are shown in Section IV. From these results, characteristics of reflection and transmission are analyzed in Section V. Finally, Section VI concludes this paper.

II. Reflection and transmission measurement Systems

As seen in Fig. 1, we compose reflection and transmission measurement systems by using a signal generator, a spectrum analyzer and directional antennas [4]-[8]. Also, we dispose a propagation absorber around the measurement system to prevent unwanted reflections. The materials used in this measurement are representative building materials, and the distance between material and antenna is 30cm. We set the material sizes as shown in Table I to prevent diffraction.

TABLE Ⅰ. The types of material

Material	Width (mm)	Height (mm)
Glass	600	610
Marble	600	400
Concrete	400	400
Particleboard	1300	600
Tile	400	248
Plasterboard	900	840
Wood	625	385

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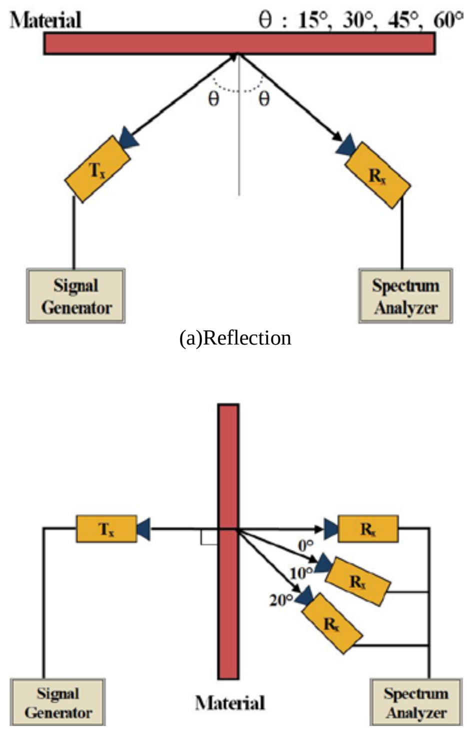

(b)Transmission

Fig 1. Reflection and transmission measurement systems

To analyze reflection and transmission characteristics according to change of angle, we change incidence and reflection angles for each reflection measurement. Also, we fix the transmission angle at vertical to the materials, and change reception angle in each transmission measurement.

In reflection measurement, if incidence and reflection angles are below 5°, propagation reflected from materials is prevented by propagation transmitted from the transmission antenna. Also, if incidence and reflection angles are greater than 75°, propagation is transmitted to the reception antenna directly, not reflected from the materials [5]. So, we restrict incidence and reflection angles to between 15° and 60° with 15° resolution. In transmission measurement, if the reception angle is greater than 30°, propagation is not received at the reception antenna, as seen in Fig. 2 regardless of frequency band and types of material.

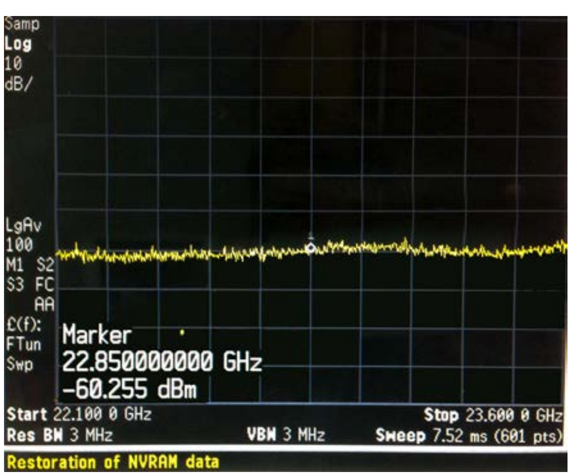

Fig 2. Transmission measurement result at a 30° reception angle

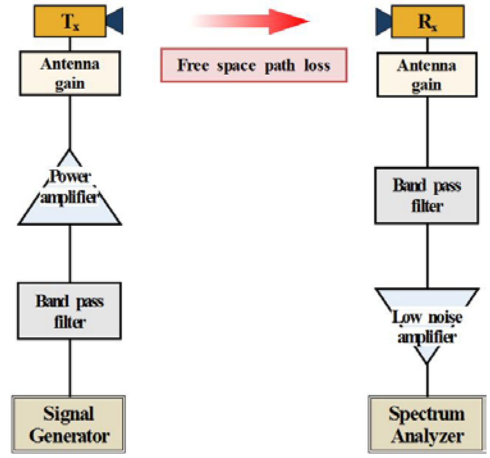

Fig 3. Measurement system

TABLE Ⅱ. Transmission power according to frequency

Frequency (GHz)	Free space path loss (dB)	System gain (dB)	Transmission power (dBm)
13.5	50.62	64.48	-50
22.85	50.62	54.37	-30
25.75	50.62	49.14	-30
28	50.62	47.46	-30

The waveform shown in Fig. 2 is the same when it is measured at the receiver without the transmitter. This is just the waveform of the noise level. So, we restrict reception angle to between 0° and 20° with 10° resolution.

In this paper, we measured reflection and transmission characteristics at 13.5GHz, 22.85GHz, 25.75GHz and 28GHz. In the measurement system in Fig. 3, because system gains are different according to frequency band, we set transmit power in each frequency band as shown in Table II before measuring reflection and transmission characteristics.

III. Reflection Measurement Results

In the reflection measurement results, the average received power readings at 13.5GHz, 22.85GHz, 25.75GHz and 28GHz are shown in Table III. We set a metal plate, where the reflection coefficient is assumed to be 1, as a reference to compare reflection characteristics according to the material [5], [6], [7], [9]. From this result, we calculated reflection loss by comparing received power for test materials and the reference material, showing them in Fig. 4.

In the results of received power in Table III and reflection loss in Fig. 4, there are no clear characteristics according to change of angle. We determined that this result is due the characteristics of the directional antenna used for measurement. In the reflection characteristics according to material, glass on average has the smallest reflection loss at -4.59dBm, and wood on average has the biggest reflection loss at -18.57dBm. In the

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TABLE Ⅲ. Received power from reflection measurement (dBm)

Degree / Material	15°	30°	45°	60°
Reference	-39.95	-39.47	-39.33	-40.81
Glass	-44.22	-42.75	-42.82	-48.12
Concrete	-45.02	-45.56	-45.43	-47.34
Marble	-46.86	-47.80	-49.22	-48.67
Tile	-48.47	-47.50	-48.89	-49.50
Particleboard	-50.65	-51.07	-50.91	-51.46
Plasterboard	-51.50	-52.00	-50.62	-52.95
Wood	-56.89	-60.00	-58.81	-58.12

TABLE Ⅳ. Received power in transmission measurement (dBm)

Degree / Material	0°	10°	20°
Reference	-35.47	-44.60	-51.67
Glass	-36.46	-46.01	-52.62
Tile	-38.08	-46.88	-54.05
Plasterboard	-39.71	-47.14	-55.09
Particleboard	-40.51	-49.13	-54.03
Marble	-41.47	-49.59	-54.72
Wood	-48.81	-53.01	-58.83
Concrete	-59.71	-59.66	-59.75

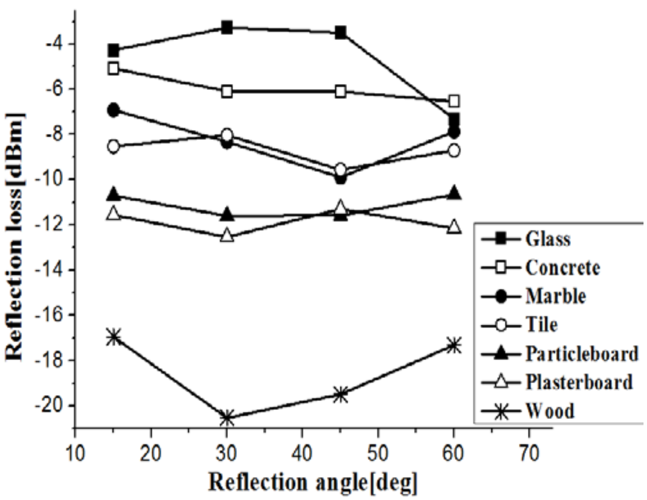

Fig 4. Reflection loss according to material

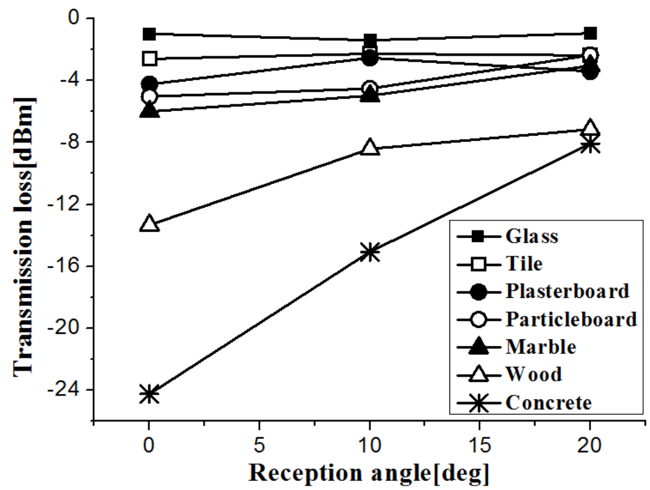

Fig 5. Transmission loss according to material

reflection measurement results, material that has a smooth surface has a smaller reflection loss.

IV. Transmission Measurement Results

In the transmission measurement results, the average received power readings at 13.5GHz, 22.85GHz, 25.75GHz and 28GHz are shown in Table IV. We set line-of-sight (LOS), where the transmission coefficient is assumed to be 1, as a base reference to compare transmission characteristics according to material [6]-[8]. From the results, we calculated transmission loss by comparing received power of the test materials and the reference material, as shown in Fig. 5.

In the results for received power in Table IV, the biggest average received power was measured when reception angle is 0°. When we changed the reception angle, average additional attenuations of -6.98dBm at 10° and -12.57dBm at 20° were generated.

In the results of transmission loss in Fig. 5, the biggest average transmission loss was measured when the reception angle is 0°. Also, it measured from -0.99dBm to -24.24dBm, according to the material. When we changed the reception angle, transmission loss measured from -1.4dBm to -15.06dBm at 0° and from -0.96dBm to -8.08dBm at 10°. It was because that received power was more sharply reduced according to the change of reception angle in LOS condition. In the transmission characteristics according to material, glass has the smallest transmission loss, and concrete has the biggest transmission loss.

V. Characteristics Analysis of Reflection and Transmission

From the reflection and transmission measurement results, we derived reflectance and transmittance to analyze reflection and transmission characteristics.

To derive reflectance, we used (1). $P_{reference}$ means received power reflected from the metal plate, $P_{material}$ means received power reflected from the material [5].

$$R = P_{material} \; / \; P_{reference(metal\ plate)} \qquad (1)$$

Reflectance according to material and change of incidence

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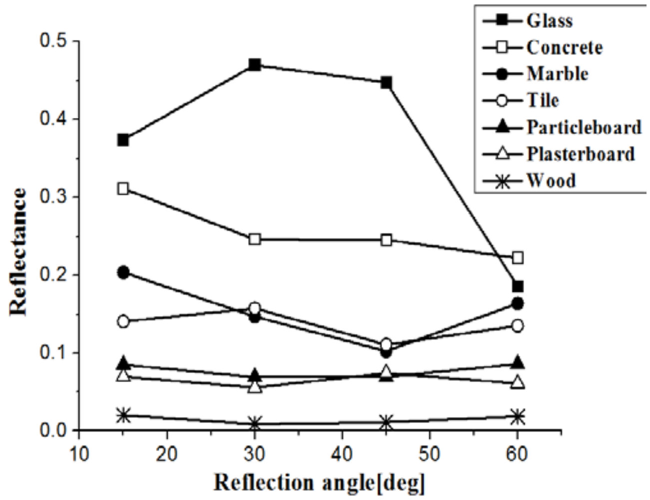

Fig 6. Reflectance according to material

and reflection angles is shown Fig. 6. In reflection measurement, when incidence and reflection angles are 30°, glass has the smallest reflection loss at -3.27dBm, and the biggest reflectance at 0.4699. On the other hand, when incidence and reflection angles are 30°, wood has the biggest reflection loss at -20.53dBm and the smallest reflectance at 0.0089. At the smallest reflectance, little propagation is received at the reception antenna. Almost all the reflectance from the materials measured between 0 and 0.5. So, there is a lot of loss when a millimeter wave is reflected from materials.

To derive transmittance, we used (2). $P_{reference}$ means received power in LOS, $P_{material}$ means received power penetrating the material [5].

$$T = P_{material} \; / \; P_{reference(LOS)} \tag{2}$$

Transmittance according to material and change of reception angle is shown Fig. 7. In transmission measurement, when the reception angle is 20°, glass has the smallest transmission loss at

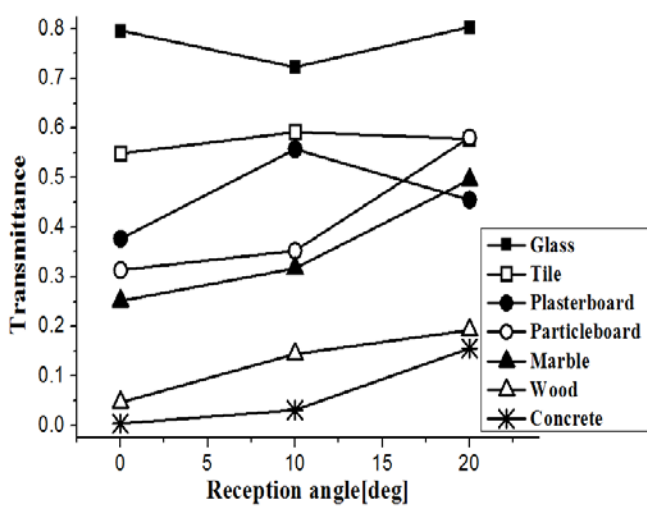

Fig 7. Transmittance according to material

TABLE Ⅴ. The maximum and minimum values of reflectance and transmittance according to material

Material	Reflectance		Transmittance	
	Max	min	Max	min
Glass	0.4699	0.1858	0.8035	0.7228
Tile	0.1574	0.1107	0.5916	0.5483
Plasterboard	0.0743	0.0058	0.5572	0.3767
Particleboard	0.0861	0.0692	0.5808	0.3133
Marble	0.2037	0.1026	0.4955	0.2512
Wood	0.0202	0.0089	0.1923	0.0463
Concrete	0.3112	0.2223	0.1556	0.0038

-0.96dBm, and the biggest transmittance at 0.8035. At the biggest transmittance, most of the propagation is received at the reception antenna. On the other hand, when reception angle is 0°, concrete has the biggest transmission loss at -24.24dBm, and the smallest transmittance at 0.0038. At the smallest transmittance, little propagation is received at the reception antenna. Almost all transmittance for the materials measured between 0 and 0.8. So, there is a lot of loss when a millimeter wave penetrates materials. But it is relatively small compared to the loss of reflection. Also, transmittance showed big differences according to material.

Table V shows the maximum and minimum values of reflectance and transmittance according to material. In reflection measurement, when a millimeter wave was reflected from the each material, more than half of propagation was lost due to attenuation. Especially, when a millimeter wave was reflected from some materials such as tile, plasterboard, particleboard and wood, most of propagation was lost due to attenuation. So, very small amount of propagation was received at the reception antenna. Also, in transmission measurement, when a millimeter wave penetrated some materials such as marble, wood and concrete, more than half of propagation was lost due to attenuation. Especially, when a millimeter wave penetrated wood and concrete, most of propagation was lost due to attenuation. So, very small amount of propagation was received at the reception antenna. In both reflection and transmission results, wood made much attenuation, and glass made little attenuation. Also, a millimeter wave was strongly affected by reflection than transmission relatively.

VI. Conclusion

In this paper, we measured and analyzed reflection and transmission characteristics according to materials and change of angle from 13GHz to 28GHz in the millimeter wave band. In each case, we measured received power and loss of reflection and transmission with comparisons to a reference material. And then, we derived reflectance and transmittance.

In the reflection measurement results, there are no clear characteristics according to change of angle. We determined that this is due to the characteristics of the directional antenna used for measurement. As for reflection characteristics according to material, glass has the smallest reflection loss and the biggest reflectance. On the other hand, wood has the biggest reflection loss and the smallest reflectance. Generally, material that has a smooth surface has a smaller reflection loss.

In the transmission measurement results, the biggest transmission loss was measured when the reception angle is 0°, and the smallest transmission loss was measured when the reception angle is 20°. As for transmission characteristics according to material, glass has the smallest transmission loss and the biggest transmittance. On the other hand, concrete has the biggest transmission loss and the smallest transmittance.

In both reflection and transmission results, there is a lot of loss when a millimeter wave reflects from and penetrates materials. In particular, when a millimeter wave reflects from the material, a lot of loss is generated.

From these results, we confirmed reflection and transmission characteristics according to material and change of angle from 13GHz to 28GHz in the millimeter wave band. As for future research, the research about characteristic analysis in millimeter wave band regarding of indoor and outdoor condition is need because millimeter wave is strongly affected by climate features. Moreover, additional research into different environments for measurements, such as antenna type, the size of the material and the frequency bands, will help to utilize the millimeter wave band and build communications systems effectively.

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