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# Terahertz Channel Measurements for Different Angles and Different Obstacles

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**Abstract**—With the development of communication technology, people's requirements for information transmission rate are getting higher and higher. Compared with the previous sub-6G frequency band, terahertz communication has larger bandwidth and higher rate. This paper studies the influence of azimuth angle of arrival (AoA) and azimuth angle of departure (AoD) on the received signal strength in the 220 GHz–320 GHz frequency band, as well as the influence of the signal passing through different obstacles, different dry humidity, and material thickness on the signal power.

## 1. INTRODUCTION

Terahertz waves refer to electromagnetic waves with a frequency range of 0.1 THz–10 THz. In order to meet the increasing demand for transmission rate and transmission bandwidth, as well as exploration of virtual reality, holographic communication and other scenarios, terahertz has become one of the key technologies in the 6G era by virtue of its ultra-high speed and ultra-large bandwidth [1].

For scenarios such as chip-to-chip, data center, short-distance equipment, and equipment in metal casings, channel modeling in the terahertz frequency band is inseparable from the support of a large amount of measured data [2–5].

In [6], the authors conducted indoor channel measurements in the millimeter-wave frequency band and studied the effects of pitch angle and AoA and AoD on the received signal. The measurement in the millimeter wave band in [6] has brought some enlightenment to our measurement in the terahertz band. In [7], the authors measured two scenarios at 300 GHz, a point-to-point connection of a desktop device and a laptop connected to an access point in the middle of the office. However, the influence of material properties on the terahertz signal has not been studied. In [8], the authors measured indoor line-of-sight (LOS) distance up to 5.5 m in the 140 GHz–220 GHz frequency band. In [8], the authors studied path loss and other parameters but was lack of research on none-line-of-sight (Nlos) environment. In [9], the authors performed channel measurements in 130 GHz–143 GHz, conference room scenarios, and developed a cluster-based channel model. [10] achieved measurements for classroom scenarios in the spectrum range from 300 GHz to 310 GHz. The terahertz channel measurement in specific scenarios is realized. However, there is a lack of research on emission angle and incidence angle. In [11], the authors performed transmission measurements in the 750 GHz to 1.1 THz frequency band for various indoor materials such as wood, plastic, and paper. This research aims to obtain material properties in terahertz band, which has a positive impact on channel modeling methods such as ray tracing. In [12], the authors compared office and industrial environments in the frequency band from 50 GHz to 325 GHz. The research focused on comparison, but no specific research on terahertz signals. [13] measured the signal performance under different spacing distances and acrylic plates with different thicknesses in

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the 900 GHz–1100 GHz frequency band and studied the ground reflection. However, the influence of humidity and angle on the terahertz signal has not been studied.

The research on channel characteristics is a key part of the communication system and the difficulty of terahertz technology. Compared with the sub-6G channel and the millimeter wave channel used by 5G, the terahertz band has a large bandwidth that can be used and can support higher communication rates. However, compared with low-frequency signals, terahertz signals have higher transmission loss and higher requirements for communication environment. The communication quality depends on the alignment of the transmitting and receiving antennas. In this paper, the measurement frequency band is mainly 220 GHz–320 GHz, and the signal strength is measured when the transmitter and receiver are rotated −30 degrees to 30 degrees, and the following contents are measured: 1. Measured the human head model, human hand model, thick cardboard, thin wood, metal sheet, kraft cardboard, foam, glass. 2. Measured the channel response of wet board and kraft cardboard and compared with dry board. 3. The terahertz signal intensity through 0 to 4 sheets of kraft cardboards was measured respectively.

The rest of this paper is as follows. Section 2 introduces the measurement system. Section 3 studies the effects of angles, obstacle materials, etc. Section 4 carries out the simulation verification. Section 5 gives conclusions.

## 2. TERAHERTZ MEASUREMENT SYSTEM

### 2.1. Measurement System

The measurement results in this paper are based on the Rohde Schwarz vector network analyzer ZVA67 and the frequency converter ZC330. The setting of measurement is shown in Figure 1. The parameters of the horn antenna are shown in Table 1.

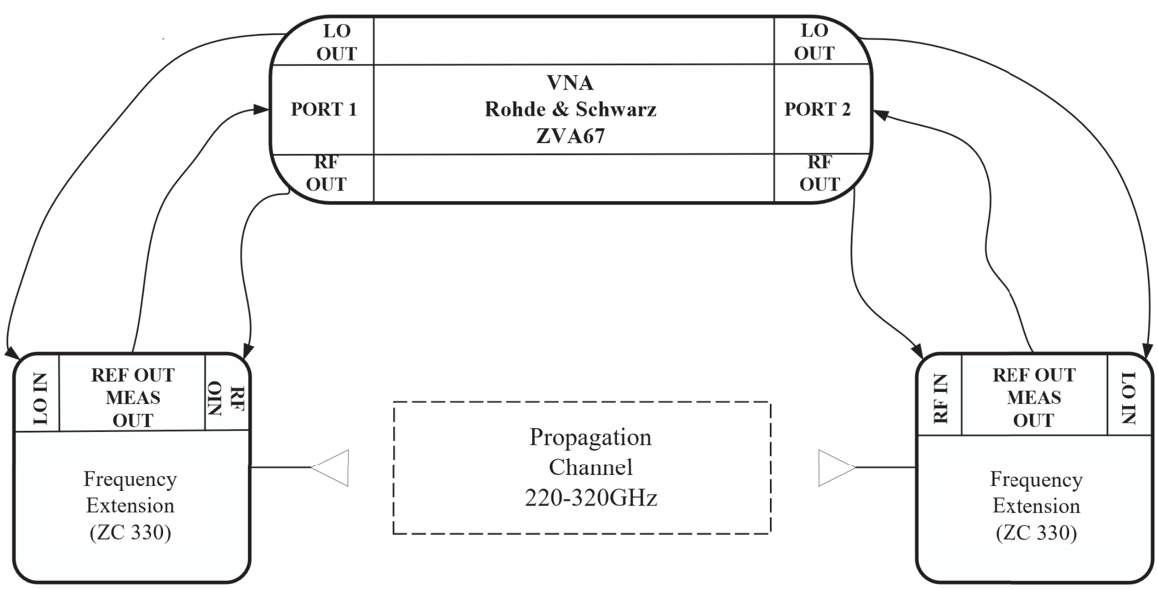



**Figure 1.** Measurement system.

### 2.2. Measurement Steps

The measurement platform is shown in Figure 2. The measurement process is carried out on a pneumatic optical platform, which ensures that the measurement process will not produce a large amount of jitter. At the same time, the transceiver antennas are placed 29 cm above the tabletop, which ensures that the metal tabletop will not affect the measurement results.

**Table 1.** Parameters of horn antenna.

| | |
|---|---|
| **Frequency** | 220 GHz–320 GHz |
| **Gain (dB)** | 24.5–26.0 |
| **Polarization mode** | Linear |
| **Beamwidth (°)** | 8 |
| **Cross isolated polarization** | 35 dB |
| **VSWR** | 1.15 : 1 |
| **Size (mm)** | $19.1 \times 19.1 \times 25.2$ |

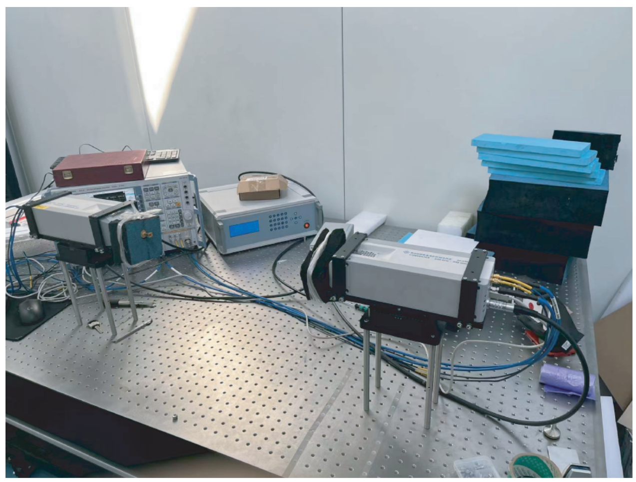


**Figure 2.** Measurement platform.

We use two automatic positioners to rotate the antenna from −30 degrees to 30 degrees and obtained the measured signal power through vector network analyzer (VNA).

## 3. ANALYSIS OF MEASUREMENT RESULTS

In this section, we will analyze the measurement results.

### 3.1. Signal Strength vs. Angle

The size of AoA and AoD will have a huge impact on signal transmission. In this experiment, we measured AoA and AoD clockwise from −30 degrees to 30 degrees, taking the midpoint of the receiver as the zero point, and obtained the corresponding channel impulse response. The power angular spectrum (PAS) is shown in Figure 3.

It can be seen from Figure 3 that the highest point of acceptance is at $(0, 0)$ point, which is the position where the antenna is aligned. When the transmitter remains stationary and the receiver is offset by 15 degrees, the received power is reduced by about 30 dB. It can be seen that the influence of the angle on the terahertz signal is huge, and the quality of terahertz communication depends on the angle of the antenna.

The diagrams in Figure 4 are the power delay profiles (PDP) with the transmitter rotated 5 degrees counterclockwise. The transmitter does not deflect in Figure 4(b). Figure 4(c) are the PDP with the transmitter rotated 5 degrees clockwise. As can be seen from Figure 4, when the transmitter antenna is rotated, the received power at this time will change accordingly. And the angle corresponding to the

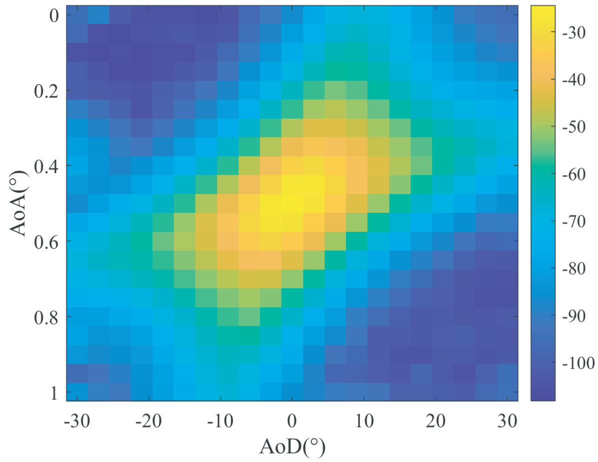



**Figure 3.** PAS of Los.

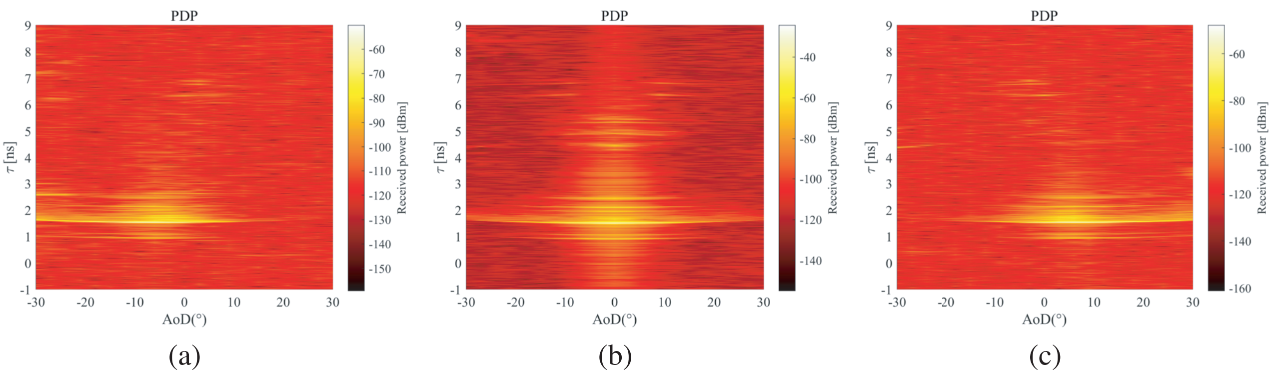



**Figure 4.** PDP of Los. (a) AoA = −5°; (b) AoA = 0°; (c) AoA = 5°.

maximum power point will also move the towards the direction close to the transmitter antenna. In the figure the yellow line symbolizing the path with the largest power will move with the change of the angle.

We compare the influence of AoD angle and AoA angle on the received power. It can be seen from Figure 5 that when the receiver and reflector deflect at the same angle, the received power is similar. It shows that the influences of AoA and AoD on the signal are similar.

In Figure 6, we compare the influence of the different angles of AoA deflection on the received signal power. It can be seen that the PDPs with AoA deflection of 15 degrees and 30 degrees are similar. And the received power is relatively small, while the size difference between the direct and deflection of 15 degrees is large, indicating that the transmission of terahertz signal has high requirements for the alignment of transceiver antenna.

Figure 7 shows the cumulative distribution function (CDF) diagram of the received power in the time domain at different angles. Under the Los condition, the received power of terahertz signal meets the Gaussian distribution at different angles, which can be characterized by the Gaussian distribution.

## 3.2. Research about Materials

We have measured several common materials, wood board ($450 * 600 * 6$ mm), kraft cardboard ($600 * 600 * 6$ mm), thick cardboard ($600 * 800 * 22$ mm), metal sheet ($300 * 300 * 4.5$ mm), glass ($518 * 95 * 6$ mm), foam ($55 * 55 * 5$ mm), human head and hand model. The materials used are shown in Figure 9. The measurement results are shown as follows.

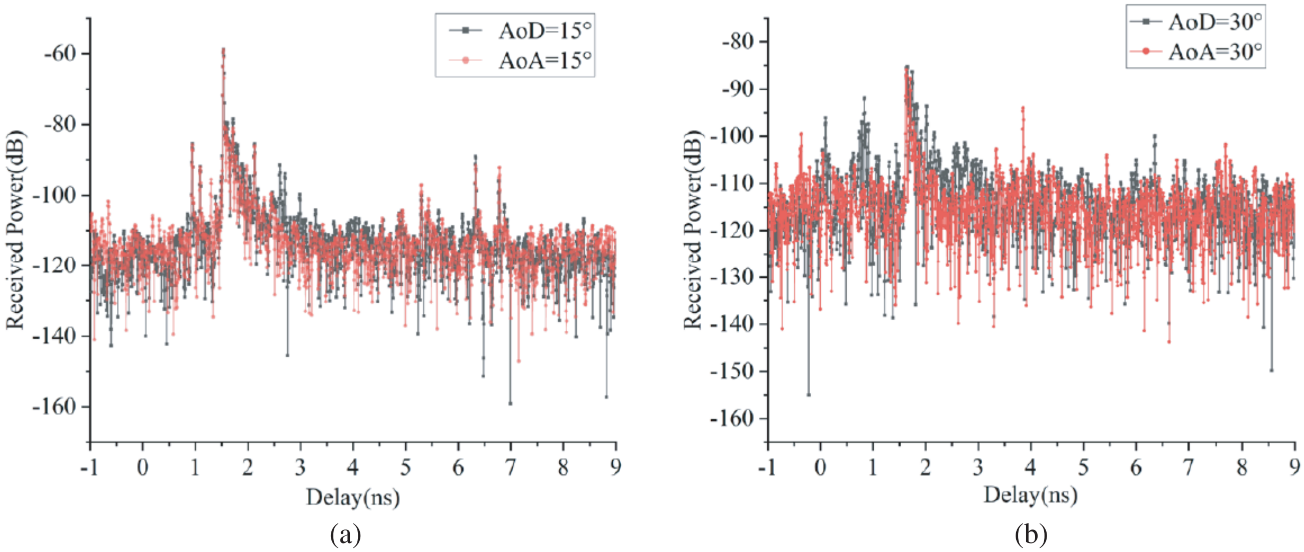



**Figure 5.** Influence of AoD and AoA on received power. (a) AoD = 15°, AOA = 15°; (b) AoD = 30°, AoA = 30°.

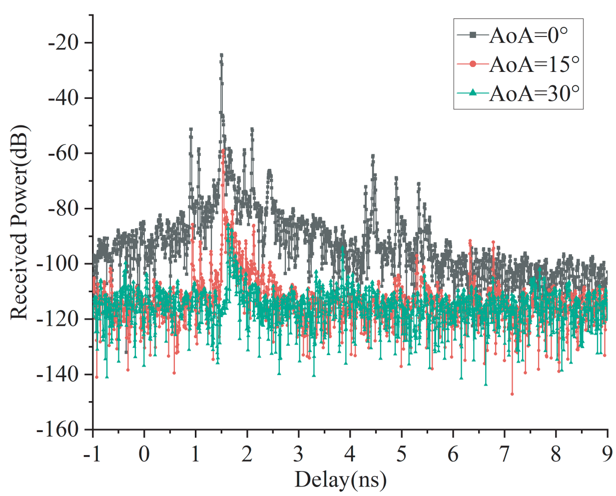



**Figure 6.** Influence of AoA size on the received power.

It can be seen from Figure 8 that the influence of wood board, cardboard, and foam board is small. The attenuation of glass is relatively large, and the positions where the path loss of these materials is the smallest are all $(0, 0)$ points, which can be adjusted with the transmission and reception antennas. The more the offset is, the greater the loss is. Compared with the influence of material change on terahertz transmission, the influence of angle change is greater.

The human head model, human hand model, and metal model have a great influence on the signal. The maximum power they received is not at the moment when the receiving antenna is aligned with the transmitting antenna, and the received power at this moment is relatively high. The point with the maximum received power is not when it is direct but when it is deflected at a certain angle. It can be seen that the loss of terahertz passing through these materials is large, and it is almost impossible to pass through these materials. But the diffraction effect is better.

As shown in Figure 10, we calculated the cumulative distribution function of the measured data and compared it with the Gaussian distribution. It can be found that the transmission between different materials also meets the Gaussian distribution. Whether it is wood board, paperboard with small loss, or metal sheet with large loss, the received signal obeys Gaussian distribution. This shows that the probability distribution of received power of terahertz signal passing through different materials can be simulated by changing the mean and variance of Gaussian function.

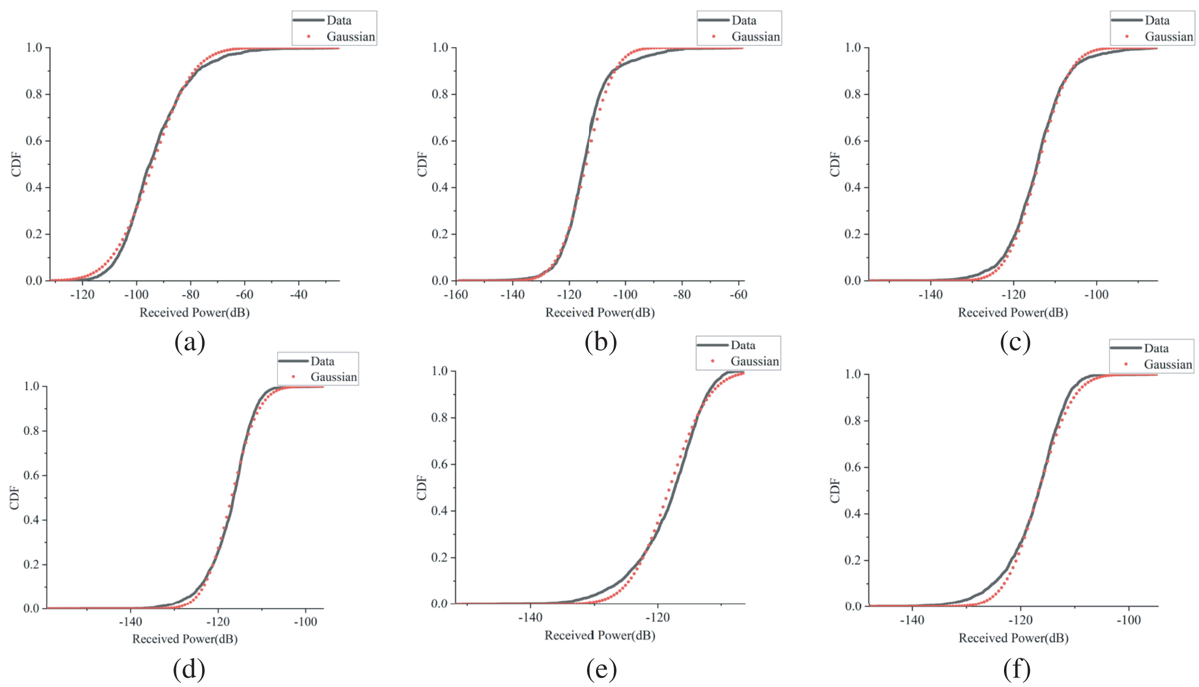



**Figure 7.** Gaussian distributed and measured distributed for LoS scenarios. (a) AoD = 0°, AoA = 0°; (b) AoD = 15°, AoA = 0°; (c) AoD = 30°, AoA = 0°; (d) AoD = 15°, AoA = 15°; (e) AoD = 15°, AoA = 30°; (f) AoD = 30°, AoA = 30°.

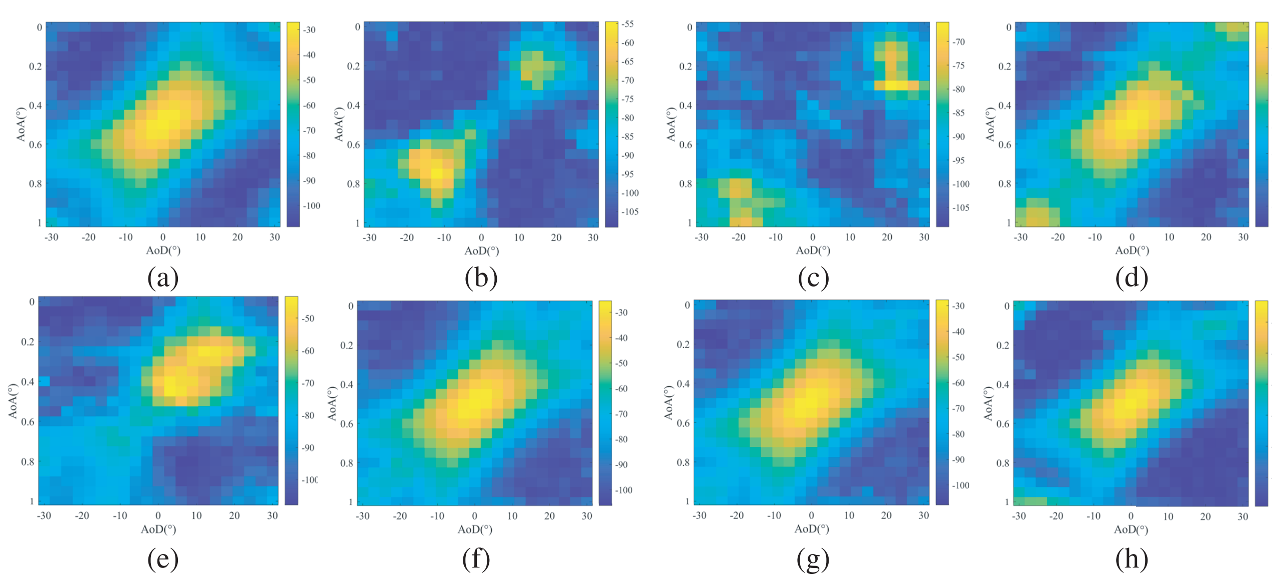



**Figure 8.** PAS of different obstacles. (a) Cardboard. (b) Sheet metal human; (c) Head model board; (d) Wood; (e) Foam board; (g) Kraft board; (h) Glass.

**Figure 9.** Materials.

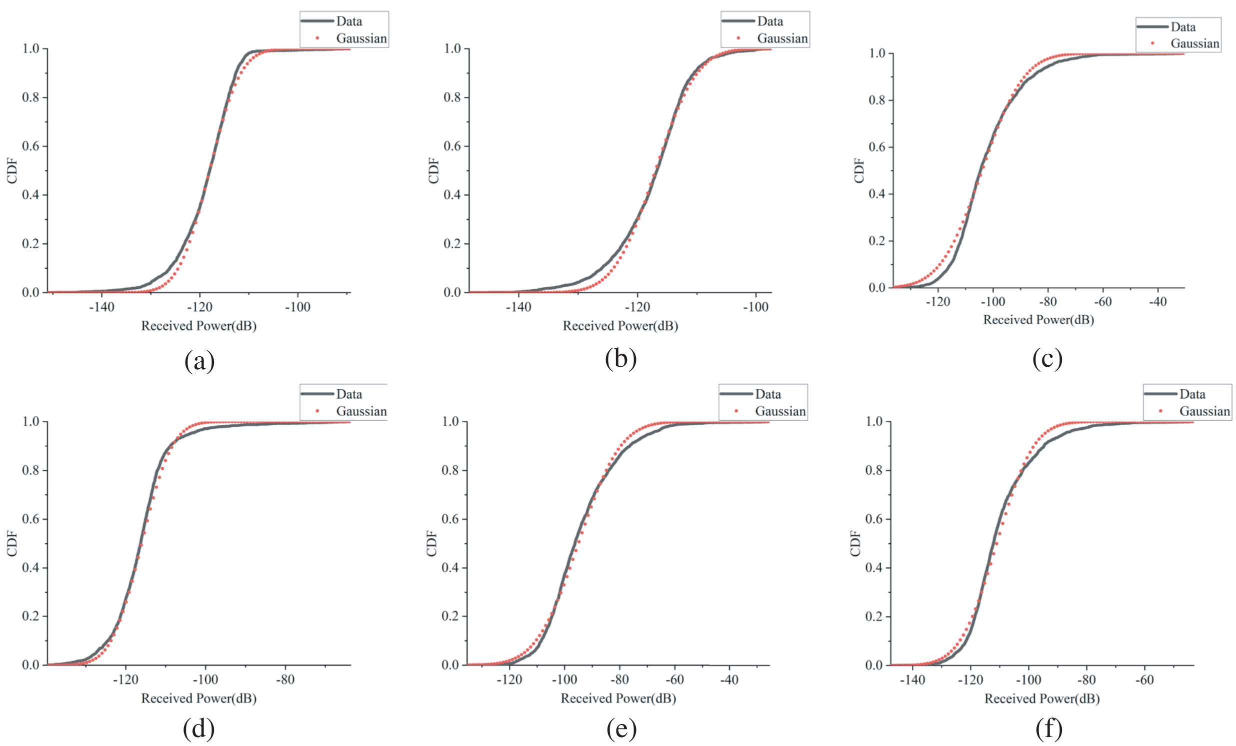



**Figure 10.** Gaussian distributed and measured distributed of different obstacles. (a) Human head model; (b) Sheet metal board; (c) Wood board; (d) Human hand model; (e) Foam board; (f) Glass.

### 3.3. Research about Humidity

The attenuation of terahertz transmission is related to weather and water vapour density [14]. To study the effect of humidity, we compare the transmission results of terahertz signal under dry or wet conditions for the same object. The results are shown in Figure 11.

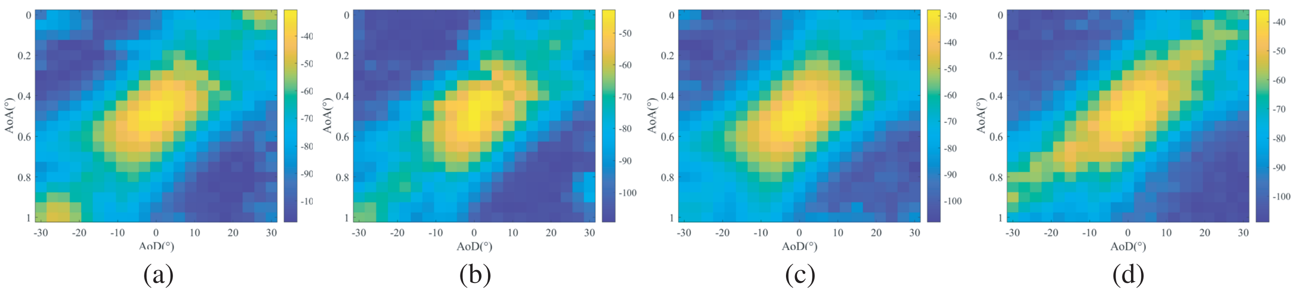



**Figure 11.** PAS. (a) Dry Wood; (b) Damp wood; (c) Dry kraft cardboard; (d) Damp kraft cardboard.

By comparing the two sets of pictures, we can see that water molecules will have a negative impact on the transmission of terahertz signals. From Figure 11, we can see that both the wood board and kraft cardboard significantly increase the attenuation of terahertz.

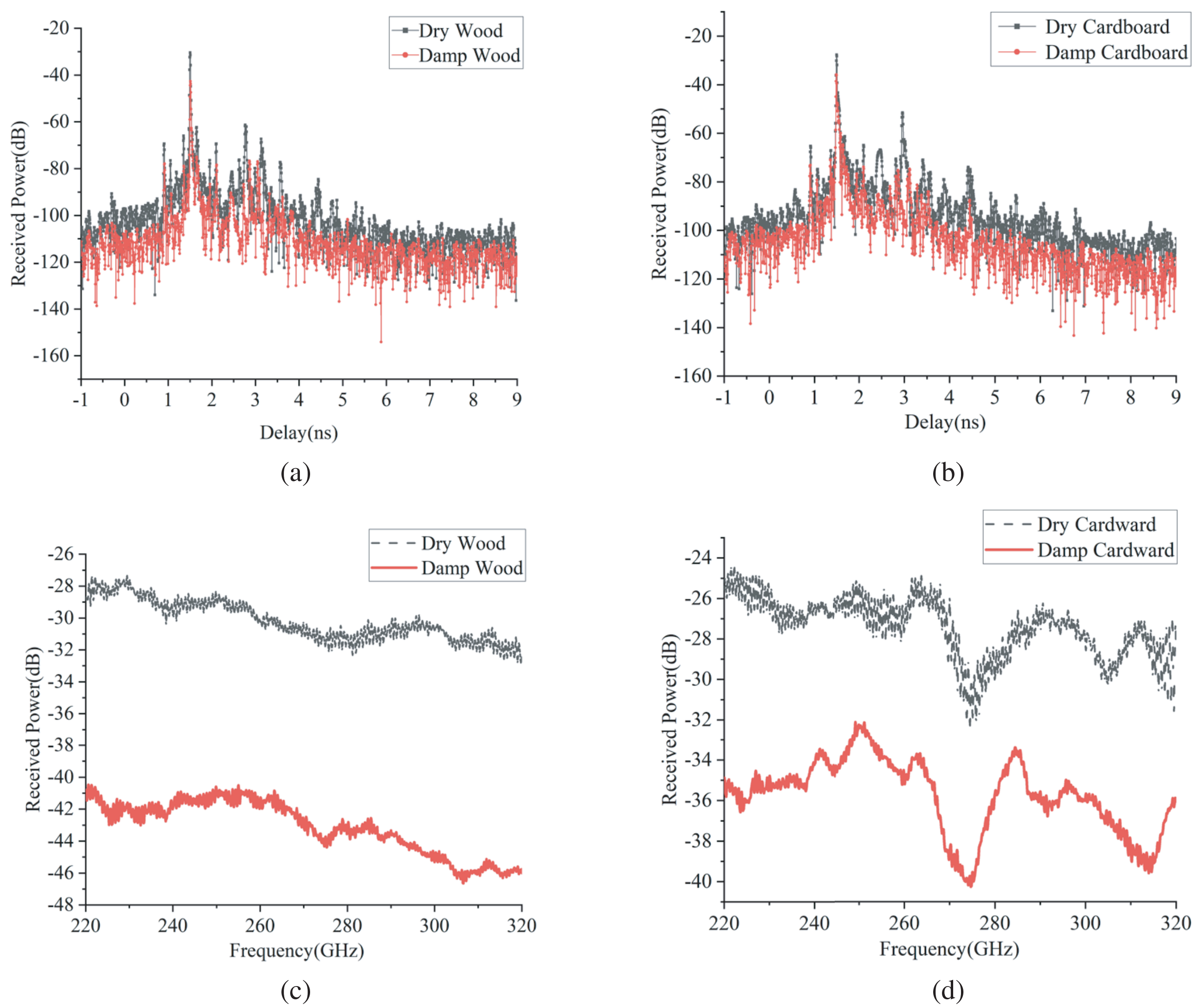



**Figure 12.** Comparsion of dry and damp board in time domain and frequency domain. (a) Dry and damp wood board in time domain; (b) Dry and damp cardward in time domain; (c) Dry and damp wood board in frequency domain; (d) Dry and damp cardward in frequency domain.

Figures 12(a) and (b) compare the changes of signal in time domain through dry and wet plates. Figures 12(c) and (d) compare the changes of signal in frequency domain through dry and wet plates. It can be seen that the impact of wet environment on terahertz signal transmission is mainly reflected in the impact of received power and has no great impact on other aspects.

### 3.4. Research about Thickness

In the actual measurement, we find that the thickness of the item is different, and the measured path loss is also different. So we prepared several kraft paper plates of the same size and thickness, and quantitatively controlled the thickness of the obstacles by controlling the number of cardboards. The materials used in the measurement are shown in Figure 13. We measured the signal impulse response of one to four cardboard sheets and compared it with the previous Los measurement results. The results are shown in Figure 14.

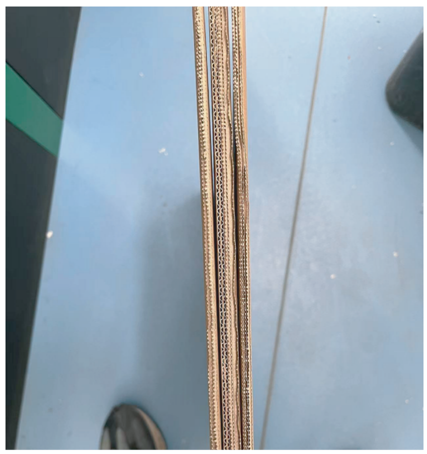


**Figure 13.** Kraft cardboards used in measurement.

As can be seen from Figure 14 and Figure 15, as the number of kraft cardboards increases, the power of the received signal also decreases gradually. When the receiving antenna is aligned with the transmitting antenna, it can be found from the figure that the reduction of the received power is proportional. Each additional piece of kraft cardboard will increase the path loss by about 3 dB.

It can be seen from Figure 15 that the transmission of the terahertz signal to the kraft paper only changes in power as the thickness of the kraft paper increases, and the signal power, frequency, and delay curves do not change much.

However, the received power of some frequency signals is very low. As can be seen in Figure 15, there is a trough when the signal is around 275 GHz. As the number of kraft papers increases, the trough becomes more and more obvious. At this time, the material's influence of thickness on the signal is relatively large, and the interval between the curves is more obvious. At some frequencies, such as around 305 GHz, it can be seen that the distance between the curves is small, and even overlap occurs in some places. It can be obtained that the influence of material thickness on the transmission of terahertz signals has different effects in different frequency bands. But generally, the relationship between $S_{21}$ and frequency is similar for the kraft board with different thicknesses.

## 4. SIMULATION VERIFICATION

In order to ensure the accuracy of our experimental data, we used the RT simulation software cloud RT developed by Beijing Jiaotong University to verify the test data [15]. First, we need to calibrate the antenna gain and transmission loss. The measured LOS and the PDP of a sheet of cardboard are used as the calibration data, as shown in Figure 16.

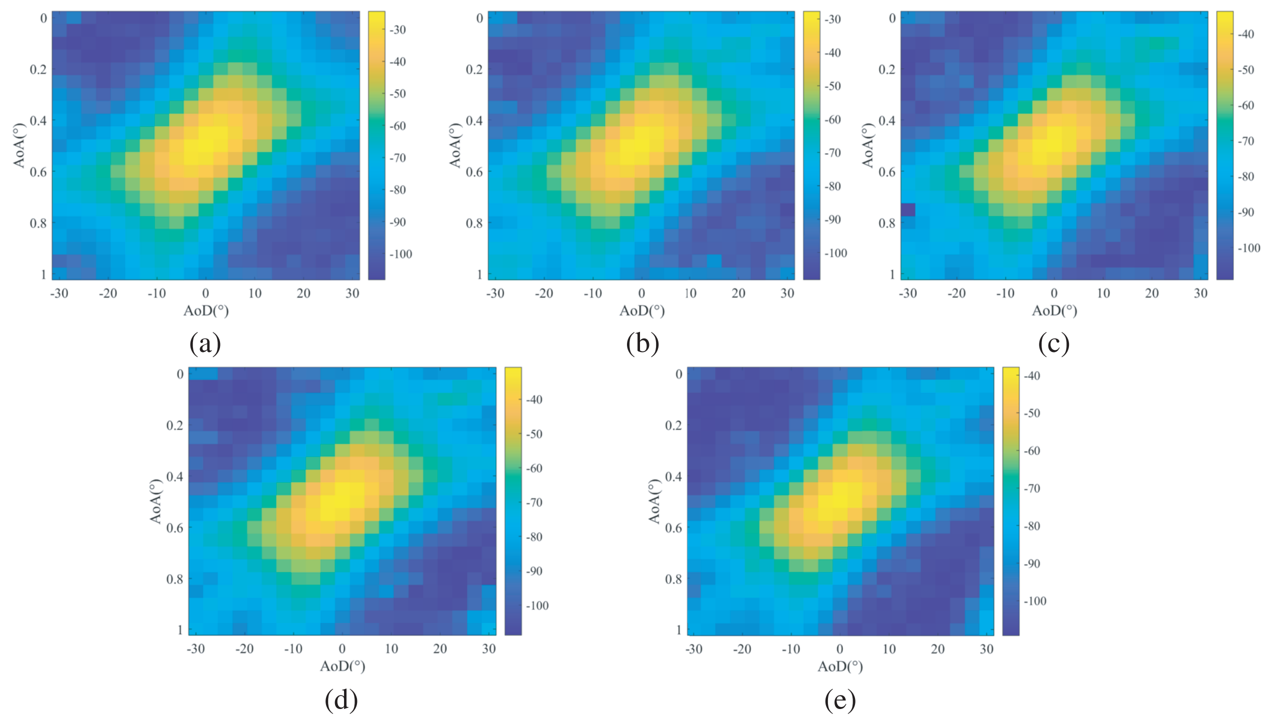



**Figure 14.** PAS of kraft cardboard with different thicknesses. (a) Los; (b) One sheet; (c) Two sheets; (d) Three sheets; (e) Four sheets.

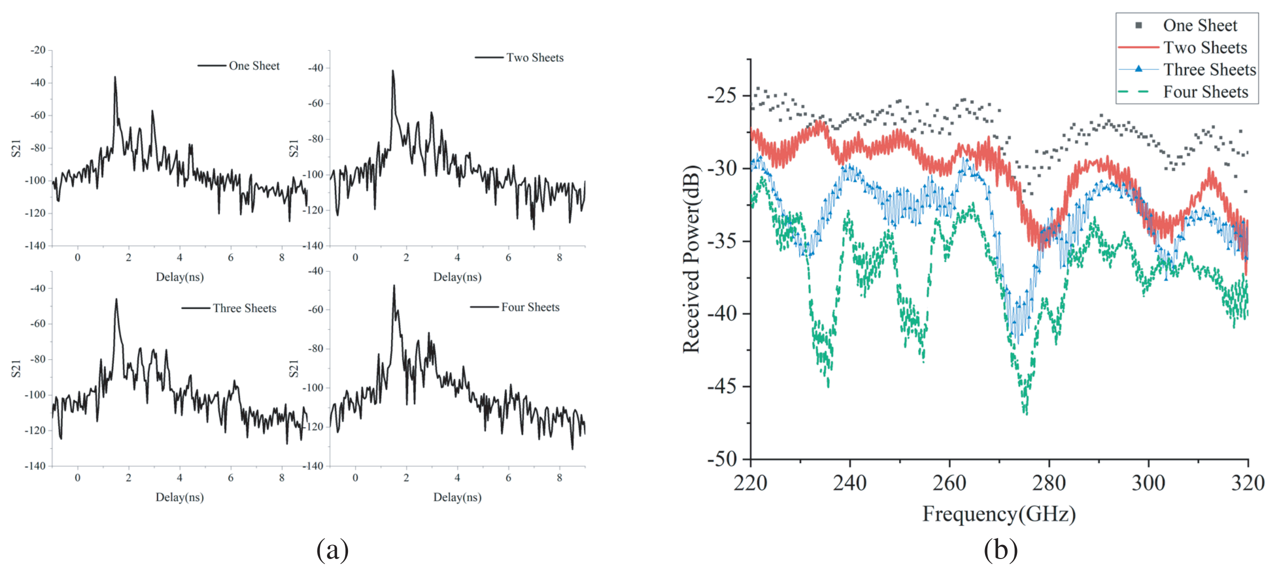
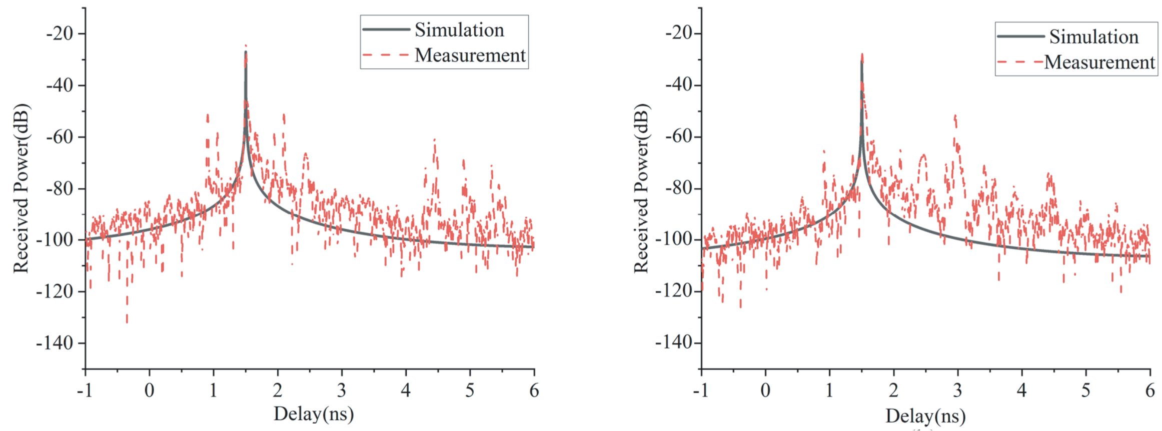


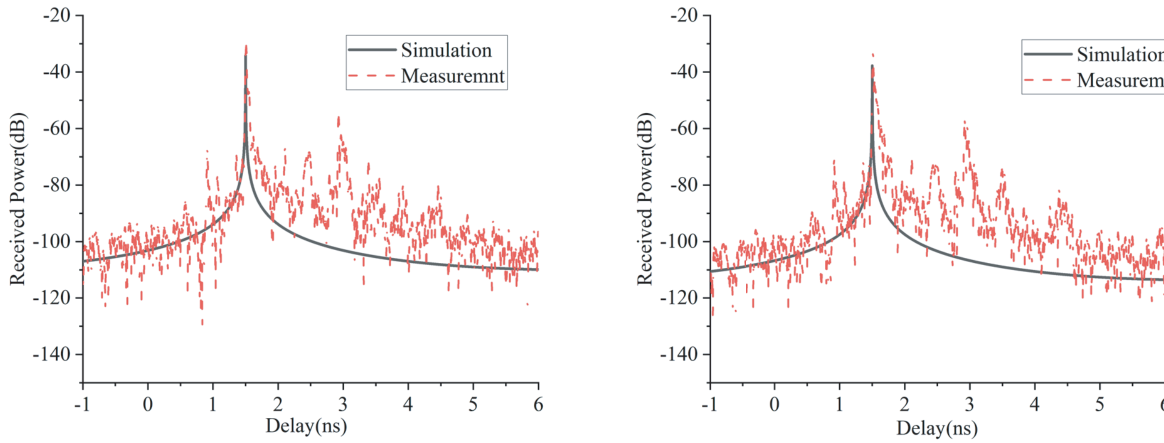

**Figure 15.** Comparison of different thickness kraft cardboard in time domain and frequency domain. (a) Kraft cardboard in time domain; (b) Kraft cardboard in frequency domain.

Then, we take the thickness of the cardboard as a variable to compare the simulation data with the measured ones, as shown in Figure 17. It can be seen that there is a peak at the time delay of about 3 ns between the measured and simulation data. According to the conclusion of [16], it can be concluded that there will be a reflected interference if the spread spectrum module is not equipped with the absorbing material during the measurement. Through comparison, we can see that the measured data are in good agreement with the simulation ones.




(a) (b)

**Figure 16.** Calibration results. (a) Los; (b) One sheet kraft cardboard.




(a) (b)

**Figure 17.** Comparison of measurement results and simulation. (a) Two sheets of kraft cardboard; (b) Three sheets of kraft cardboard.

## 5. CONCLUSION

In this article, through channel measurement, we can draw the following conclusions.

(1) First of all, the angle has a great influence on the terahertz propagation, and a little offset of the antenna will have a great influence on the terahertz propagation.

(2) Secondly, the loss of terahertz propagation has a great relationship with the material, such as foam board and cardboard. Materials such as wooden boards have less influence on terahertz, while metals and human head models have a greater impact on terahertz. Then there is the influence of moisture. Compared with dry state, wet wooden board and cardboard have a great increase.

(3) Finally, there is an effect of thickness. The greater the thickness is, the greater the loss is, and the attenuation value is basically proportional to the thickness.

## ACKNOWLEDGMENT

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