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A Solution to Get Antenna Pattern Based on Axis Calibration Between Different Mm-wave Measurement Platforms

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Abstract—**Mm-wave is expected to be one of the important technologies for 5G wireless communication system, and it is necessary for us to study its radio propagation characteristics, which is helpful for channel modeling. Since we have to carry out a large number of channel measurement campaigns, obtaining the antenna pattern of mm-wave horn antenna on different rotating platforms in different scenarios is an important but difficult work. In this paper, we propose an axis calibration method that just needs to measure the antenna pattern once in the anechoic chamber and do a simple measurement in the practical application scenario, then the exact antenna pattern on different rotating platforms can be calculated out based on previous measured antenna pattern in the anechoic chamber, which can save much measuring time. What is more, we also use simulation and practical channel measurement experiment to validate the accuracy of the proposed method, and the relationship between SNR and axis error is analyzed.**

Keywords—***mm-wave measurement platform; antenna pattern;axis calibration***

I. Introduction

The growth of mobile data has created unprecedented challenges for wireless communication, and one of the important problems is shortage of communication bandwidth. At present, the main spectrum of wireless mobile communication is just from 700MHz to 2.6GHz, which motivates the exploration of the mm-wave frequency spectrum [1][2]. In order to make use of mm-wave, a large number of channel measurement campaigns have been carried out. [3][4][5] study radio propagation characteristics of mm-wave in dense urban environment. If we have comprehensive knowledge of channel characteristics in all kinds of scenarios, accurate channel model [6][7][8] could be built to evaluate new mm-wave communication system, so channel measurement campaigns are important and urgent work at present.

Since mm-wave has relatively high atmospheric attenuation [1], we usually use directional horn antenna and rotating platform to obtain channel impulse response. Then channel estimation algorithm will be used to calculate channel parameters based on antenna directional pattern on different rotating platforms. Since mm-wave technology needs to be applied in different scenarios [2], the measurement platforms are usually different and the antennas are installed on different support stands. When measurement frequency is fixed, the same type of antenna will be used.

If the antenna pattern measured on previous platform is applied to the new measurement platform when switching the platform based on application scenario, because the wavelength of mm-wave is very short, slight misalignment will result in larger phase error, which will have bad effect on channel parameters analysis and channel modeling. What is more, measuring exact antenna pattern is a difficult and complex work, and some platforms are too large to be placed in small anechoic chamber, for example, the rotating platform on the roof of vehicle. So we would like to propose a new scheme to solve this problem.

At present there is little study on axis calibration between different measurement platforms. In order to find antenna phase center [9], the researchers usually use moving reference point method [10] or specialized platform [11] to obtain more precise result. In order to find rotating center of mechanical platform, the researchers usually use location calibration method [12] or global optimization [13]. The above methods' key idea is to find absolute error, such as phase error or position error, and the detecting experiment is burdensome, most of which need complex experimental system.

This paper presents an axis calibration scheme which can be adapted to different measurement scenarios. We obtain the antenna pattern on experimental rotating platform by one-time measurement in anechoic chamber, and measure main lobe pattern of the same antenna on the rotating platform in application scenario. Then we use the new scheme to calibrate axis error between two rotating platform, and the new antenna pattern suitable for new rotating platform can be obtained, which will save a lot of measuring time.

The remaining paper is structured as follows. Section II presents channel propagation scenario and axis calibration scenario. Section III introduces angle alignment and axis calibration methods. Section IV describes simulation experiment and Section V describes channel measurement experiment. Section VI concludes the work.

II. SYSTEM SCENARIO

Consider a practical channel propagation scenario in Fig.1 with reflectors around, the channel between the transmitter and the receiver maybe multiple paths, including the LOS paths and NLOS paths. Each path experiences different reflections and has different travelling angles.

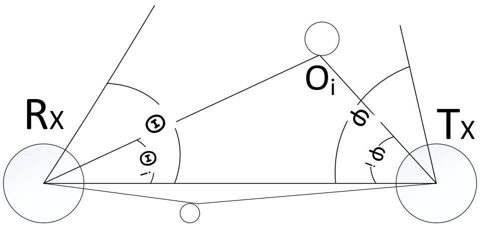

Fig. 1. Channel propagation scenario

The signal response in practical scenario can be described as follows,

$$\mathrm{g}(\theta,\varphi)=\sum_i h_i h_r'(\theta-\theta_i)h_t'(\varphi-\varphi_i) \quad (1)$$

$h_r(\theta)$ is receiving antenna pattern and $h_t(\varphi)$ is transmitting antenna pattern, which are both exact antenna patterns measured on experimental rotating platform in anechoic chamber. θ and φ are platform's rotating angle, θ_i and φ_i are the angle of arrival/departure of the i-th propagation path, and the boresight orientation is 0° when the transmitter points towards the receiver. h_i is channel response of the i-th propagation path. h_r' and h_t' are antenna patterns on practical rotating platform after axis calibration.

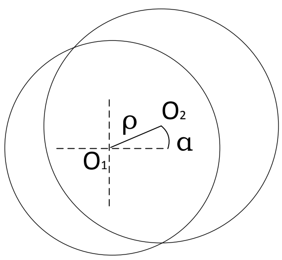

Fig. 2. Axis calibration scenario

Consider a practical axis calibration scenario in Fig.2, as for transmitter or receiver, the position of axis on previous rotating platform is O_1, but the position of axis on practical rotating platform is O_2, the figure shows that axis error is (ρ,α). The most important problem is to figure out axis error based on measured data.

III. AXIS CALIBRATION METHOD

The axis calibration method consists of two steps, angle alignment and axis calibration, which is suitable for different mm-wave application scenario.

A. Angle alignment

Since application scenario is usually different from previous one, so we should use angle alignment method to make the previous antenna pattern match new scenario. We take receiver as the example to introduce the method, the same is to transmitter.

Consider $h_r(\theta)$ is receiving antenna pattern measured on previous rotating platform in anechoic chamber, and $h_R(\theta)$ is receiving antenna's main lobe pattern measured on practical platform in application scenario. The relationship of angles between different scenarios can be expressed as

$$h_R(\theta-\theta_1)=\alpha h_r(\theta-\theta_1-\Delta\theta)+n(\theta) \quad (2)$$

Where θ_1 is the practical direction of arrival, $\Delta\theta$ is the angle error between $h_r(\theta)$ and $h_R(\theta)$, α is the amplitude ratio between $h_R(\theta)$ and $h_r(\theta)$, and $n(\theta)$ is white Gaussian noise.

The $\Delta\theta$ is unknown, so in order to obtain accurate result, we define the matching error as

$$e(\alpha,\Delta\theta)=\sum_\theta \left\| h_R(\theta)-\alpha h_r(\theta-\Delta\theta)\right\| \quad (3)$$

Where θ is the angle of antenna's main lobe measured on practical platform.

By minimizing matching error $e(\alpha,\Delta\theta)$ to obtain angle error, steps are as follows.

- Set the search range and give $\Delta\theta$ an initial value $\Delta\theta_0$.
- Use the vector projection principle to calculate α_i.

$$\alpha_i=\frac{<h_R(\theta),h_r(\theta-\Delta\theta_i)>}{\left\|h_r(\theta-\Delta\theta_i)\right\|^2} \quad (4)$$

- Calculate the matching error $e_i(\alpha_i,\Delta\theta_i)$.
- Change $\Delta\theta_i$ and repeat step 2 and 3, then find minimum matching error in search range to obtain optimal combination $(\alpha_{\min},\Delta\theta_{\min})$.
- $h_r(\theta-\Delta\theta)$ is the exact receiving antenna pattern measured on previous rotating platform matching new scenario.

B. Axis calibration

1) Illustration

Fig.3 illustrates the axis calibration method in polar coordinate system. O_1 is the position of previous rotating platform's axis, whose direction of bell-mouth is O_1A_1, and O_2 is the position of practical platform's axis in application scenario. Consider polar coordinate's origin is O_1, and O_2 is in the first quadrant, whose coordinate is (ρ,α).

Since O_2 is the center of rotation, when measured angle rotates θ degree based on the direction of arrow in Fig.3, the O_1 moves to O_1', whose direction of bell-mouth is $O_1'A_1'$. According to the geometric relationship, the rotating angle of $O_1'A_1'$ is also θ, which means the rotating angle of previous platform is the same to the practical platform's.

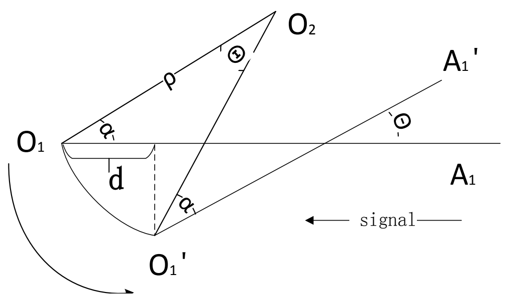

Fig.3.Illustration of axis calibration method

2) Misalignment factor

Consider the direction of signal is always $\overrightarrow{A_1O_1}$, the relative reduction in propagation path is d after measured angle rotates θ degree, which defines as the misalignment factor. According to the geometric relationship, d can be calculated as

$$d = 2\rho\sin\frac{\theta}{2}\cos(\frac{180-\theta}{2}-\alpha) \qquad (5)$$

Where (ρ,α) is the coordinate of O_2, and θ is the rotating angle.

There are 16 kinds of cases that α and θ are both from the first quadrant to the fourth quadrant, but the expression of d is the same one, we just need to change its sign which represents the increase or decrease of propagation path. For example, the rotating axis is on the first quadrant and angle θ rotates to the forth quadrant in Fig.4.

relative increase path d can be calculated as

$$\begin{aligned} d &= 2\rho\sin(\frac{360-\theta}{2})\cos(180-\alpha-\frac{\theta-180}{2}) \\ &= -2\rho\sin\frac{\theta}{2}\cos(\alpha-\frac{180-\theta}{2}) \end{aligned}$$

Which means the relative decrease path is

$$d = 2\rho\sin\frac{\theta}{2}\cos(\alpha-\frac{180-\theta}{2})$$

In summary, the expression of d is as follows.

$$\begin{aligned} d_r &= 2\rho_r\sin\frac{\theta}{2}\cos(\frac{180-\theta}{2}-\alpha_r) \\ d_t &= 2\rho_t\sin\frac{\theta}{2}\cos(\frac{180-\theta}{2}-\alpha_t) \end{aligned} \qquad (6)$$

Where (ρ_r,α_r) is the axis error of receiver, and (ρ_t,α_t) is the axis error of transmitter.

Because the wavelength of mm-wave is short, we can get new transmitting antenna pattern and receiving antenna pattern on practical platform based on far-field assumption in common propagation environment.

$$\begin{aligned} h_r'(\theta) &= \xi_r h_r(\theta)\mathrm{e}^{j2\pi\frac{d_r}{\lambda}} \\ h_t'(\theta) &= \xi_t h_t(\theta)\mathrm{e}^{j2\pi\frac{d_t}{\lambda}} \end{aligned} \qquad (7)$$

Where $h_r(\theta)$ and $h_t(\theta)$ are the exact antenna patterns measured on previous rotating platform after angle alignment, ξ_r and ξ_t are amplitude ratios between new antenna pattern and previous antenna pattern, and λ is the signal wavelength. So this method is suitable for different frequencies of mm-wave.

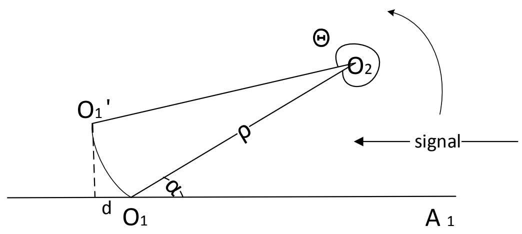

Fig.4. The forth quadrant case

3) Axis error calculation

Based on the conclusion above, we should use axis calibration method to calculate axis error to get exact antenna pattern on practical platform, and we also take receiver as the example to introduce the method, the same is to transmitter.

Since the mm-wave has strong directional property, and energy of other paths is much less than that of direct path, we only take direct path into account to analyze this problem. According to channel propagation model, the signal response in practical scenario can be expressed as

$$\begin{aligned} \mathrm{g}(\theta,\varphi) &= h_1 h_r'(\theta-\theta_1)h_t'(\varphi-\varphi_1) \\ &= h_1\xi_r h_r(\theta)\mathrm{e}^{j2\pi\frac{d_r}{\lambda}}\xi_t h_t(\varphi)\mathrm{e}^{j2\pi\frac{d_t}{\lambda}} \\ &= h_r(\theta)\mathrm{e}^{j2\pi\frac{d_r}{\lambda}}\beta(\varphi) \end{aligned} \qquad (8)$$

$$\beta(\varphi) = h_1\xi_r\xi_t h_t(\varphi)\mathrm{e}^{j2\pi\frac{d_t}{\lambda}} \qquad (9)$$

Where h_1 is the channel response of the direct propagation path, θ_1 and φ_1 are the angle of arrival/departure of the direct propagation path, which are usually 0°. Since we only take receiver into account, and transmitter's rotating angle is always 0°, $\beta(\varphi)$ can be treated as a constant.

The unknown parameters are $\rho_r, \alpha_r, \beta(\varphi)$, so in order to obtain accurate result, we should use joint estimate method. The matching error is defined as

$$e(\rho_r, \alpha_r, \beta(\varphi)) = \sum_{\theta} \| g(\theta, \varphi) - h_R(\theta) \| \qquad (10)$$

$$(\rho_r, \alpha_r) = \underset{(\rho_{rk}, \alpha_{rk})}{\operatorname{argmin}} \{ e(\rho_{rk}, \alpha_{rk}, \beta_k(\varphi)) \} \qquad (11)$$

Where θ is the angle of antenna's main lobe measured on practical platform. By minimizing matching error to obtain axis error, steps are as follows.

- Set the search range and give (ρ_r, α_r) an initial value (ρ_{r0}, α_{r0}).
- Use the vector projection principle to obtain $\beta_k(\varphi)$

$$\beta_k(\varphi) = \frac{< h_r(\theta) e^{j2\pi \frac{d_{rk}}{\lambda}}, h_R(\theta) >}{\left\| h_r(\theta) e^{j2\pi \frac{d_{rk}}{\lambda}} \right\|^2} \qquad (12)$$

- Calculate the matching error $e_k(\rho_{rk}, \alpha_{rk}, \beta_k(\varphi))$.
- Make two-dimensional search on ρ_{rk}, α_{rk} and repeat step 2 and 3, find minimum matching error in search range to obtain optimal combination $(\rho_r, \alpha_r, \beta(\varphi))$.

IV. Simulation Experiment

A. *Simulation scenario*

In this section, we provide simulation experiment to demonstrate the axis calibration method. Fig.5 shows the simulation scenario. The position of antenna phase center is O, the position of rotating axis on platform A is O_1 whose error is $\rho_1 = 2cm, \alpha_1 = 30^\circ$ based on O, and the position of rotating axis on platform B is O_2 whose error is $\rho_2 = 2cm, \alpha_2 = 45^\circ$ based on O_1. According to geometric relationship, the coordinate of O_2 can be expressed as

$$\begin{aligned} \rho_2' &= \sqrt{(\rho_2 \cos\alpha_2 + \rho_1 \cos\alpha_1)^2 + (\rho_2 \sin\alpha_2 + \rho_1 \sin\alpha_1)^2} \\ \alpha_2' &= \arctan\left(\frac{\rho_2 \sin\alpha_2 + \rho_1 \sin\alpha_1}{\rho_2 \cos\alpha_2 + \rho_1 \cos\alpha_1}\right) \end{aligned} \qquad (13)$$

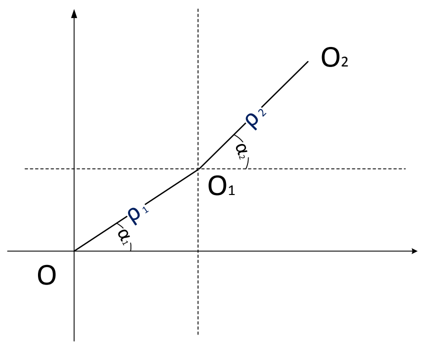

Fig. 5. The simulation scenario

Consider O is original point, and signal frequency is 19GHz. $h_1(\theta)$ is the exact antenna pattern measured on rotating platform A whose absolute axis error is (ρ_1, α_1), and $h_2(\theta)$ is the antenna's main lobe pattern measured on rotating platform B whose absolute axis error is (ρ_2', α_2'). We should use axis calibration method to calculate relative axis error to get exact antenna pattern on platform B.

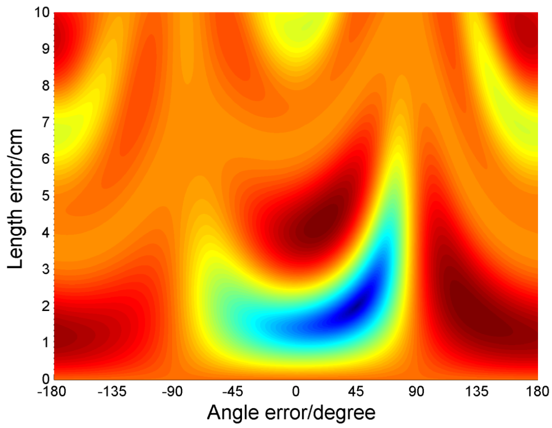

Fig.6 Matching error result

Fig.6 shows the matching error result of different axis error, the search range of angle error is from -180° to 180°, and the search range of length error is form 0 to $10cm$. The darkest point represents the minimum matching error, so axis error between two platforms is $\rho_2 = 2cm, \alpha_2 = 45^\circ$.

B. *Error analysis*

Since there will be noise affection in practical scenario, we add Gaussian noise to carry out error analysis when other conditions are the same. The practical error is (ρ_2, α_2), and the simulation result is (ρ_0, α_0), so the estimation error can be defined as the distance between position of practical axis and estimation axis.

$$\rho_{error} = \sqrt{(\rho_0 \cos\alpha_0 - \rho_2 \cos\alpha_2)^2 + (\rho_0 \sin\alpha_0 - \rho_2 \sin\alpha_2)^2} \qquad (15)$$

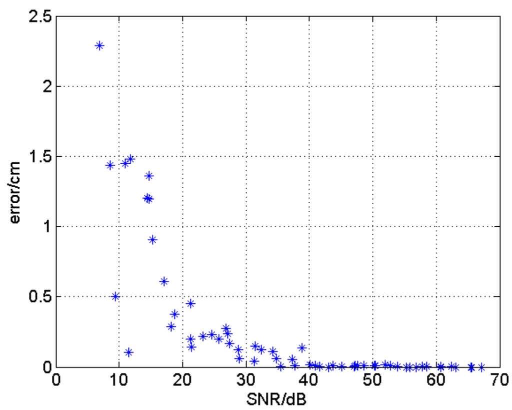

Fig.7. The relationship between error and SNR

Fig.7 shows the relationship between estimation error and SNR. The estimation error can be negligible when $SNR \geq 35dB$, and the error is less than 0.3cm in most cases when $20dB \leq SNR \leq 35dB$. But when $SNR \leq 20dB$, the error will be near to practical error which increases on exponential trend. So in order to obtain the accurate result of axis error, we should make sure $SNR \geq 20dB$.

V. CHANNEL MEASUREMENT EXPERIMENT

A. Measurement scenarios

In this section, we provide practical channel measurement experiment to demonstrate the axis calibration method.

The first scenario is the anechoic chamber. We select two high-gain horn antennas as transmitter and receiver, and install them on the mechanical rotating platform which can be automatically controlled. The exact antenna pattern is measured on the rotating platform with frequency from 19GHz to 26GHz, and the measuring accuracy is 1°.

The second scenario is the 4-408 room of FIT building in Tsinghua University. We select the same horn antennas as above, transmitting antenna is installed on mechanical rotating platform and receiving antenna is installed on rotatable tripod. Fig.8 shows the practical application scenario, the red points are the position of transmitter and receiver, and the north direction is 0°. At first, the transmitter and receiver are pointed directly at each other. Next, the receiver is steered to scan 360° across the entire azimuth horizon by 5° increment with frequency from 19GHz to 26GHz.

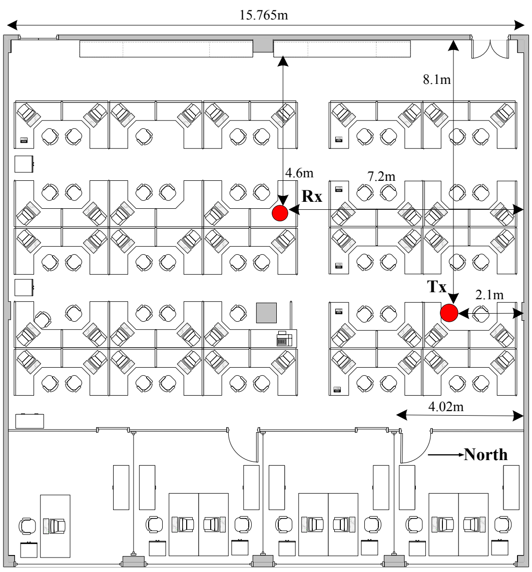

Fig.8. Practical application scenario

B. Analysis of experimental results

Consider $h_t(\theta)$ and $h_r(\theta)$ are exact antenna patterns measured on mechanical rotating platform in anechoic chamber, $h_R(\theta)$ is receiving antenna pattern measured on tripod in 4-408 room. According to the angle alignment method, at first we make the reference direction of anechoic chamber match the 4-408 room's, then move the angles together to make sure that the direction of 0° is the connection between transmitter and receiver.

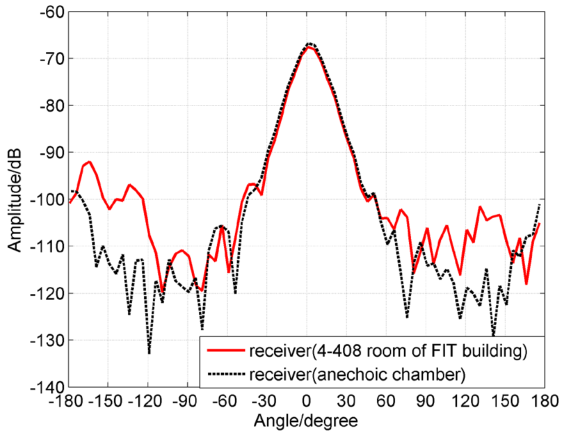

Fig.9. Angle alignment

Fig.9 shows the result of angle alignment when the signal frequency is 26GHz, and we uses projection algorithm to make the amplitude of $h_R(\theta)$ match $h_r(\theta)$. The boresight orientation is 0° when the transmitter points directly towards the receiver antenna, which contains the main lobe. Since the SNR is bad in the middle of antenna pattern, and we usually only need measure main lobe pattern of $h_R(\theta)$, we choose the data of main lobe to calculate the matching error and the gap of amplitude between lobe and the peak is less than 20dB. Consider the position of axis on previous rotating platform in anechoic chamber is O_1, and the position of axis on tripod is O_2, the axis error between O_1 and O_2 is $\rho_r = 3.4mm, \alpha_r = 163.7^\circ$, whose search accuracy is $(0.1mm, 0.1^\circ)$. So we could get new antenna pattern $h_r'(\theta)$ which is suitable for rotatable tripod.

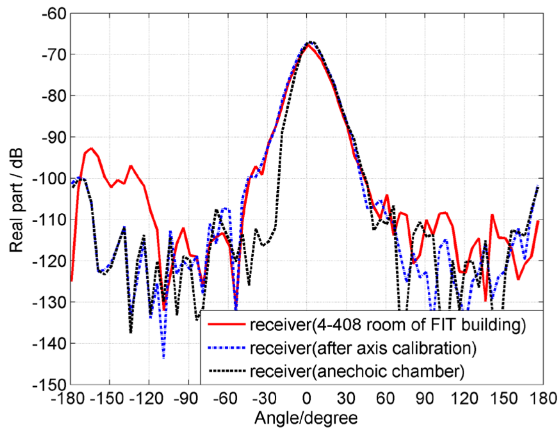

Fig.10. Real part of antenna patterns

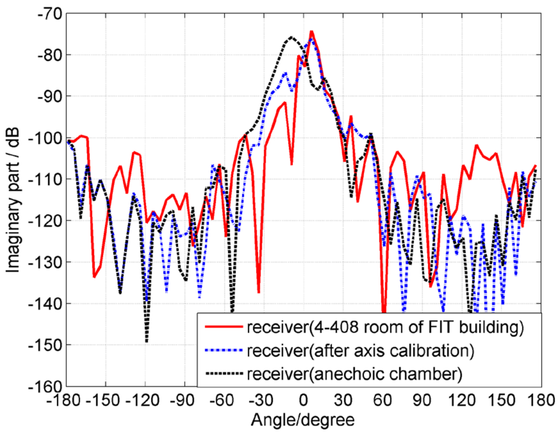

Fig.11. Imaginary part of antenna patterns

Fig.10 and Fig.11 shows the comparison of applied result between two methods, and they respectively shows the antenna pattern's real part and imaginary part. In each picture, the red line describes the $h_R(\theta)$ which is the practical antenna pattern on rotatable tripod, the blue line describes the $h_r'(\theta)$ which represents the new method that uses axis calibration to get new antenna pattern suitbale for rotatable tripod, the black line describes the $h_r(\theta)$ which represents the former method that the antenna pattern measured on previous platform is directly applied to the rotatable tripod. Consider the main lobe of antenna pattern, whose angle is from -30° to 30°, Fig.10 shows that there is little difference between each antenna pattern on real part but the $h_r'(\theta)$ is more close to $h_R(\theta)$ when the angle is from -30° to 0°. Fig 11 shows the blue line is close to red line and the peak of black line points to another direction, which means that $h_r'(\theta)$ is close to $h_R(\theta)$ on imaginary part. In summary, we could use the axis calibration method to get more accurate antenna pattern. As for the other angle of antenna pattern, the advantage of new method is not obvious since the SNR is very bad, which also validates the result of simulation experiment.

VI. CONCLUSION

In this paper, we propose the axis calibration method for mm-wave channel measurement campaigns. We obtain exact antenna directional pattern on experimental rotating platform by one-time measurement in anechoic chamber, and measure main lobe pattern of the same antenna on practical rotating platform, then we use the new scheme to figure out axis error between two rotating platforms, so we can obtain the new exact antenna pattern suitable for practical rotating platform in application scenario.

The axis calibration method makes use of channel propagation model and geometry relationship to solve improtant practical problem, and the axis error's accuracy is up to mm level when applied to practical channel measurement. This method is suitable for different freqency and different application scenario, which will reduce a lot of measuring work.

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