Impact on the Performance of Compact Antenna Test Range due to Surface Deviation of the Reflector

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Abstract— The fabrication precision of designed compact antenna test range (CATR) impacts the performance of quiet zone, especially in millimeter wave range. In this paper, several surface deviations of the reflector and their influence on the quiet zone are analyzed. Comparing the data of deviated reflector with those of the ideal reflector, it is found that the sensitivity of quite zone to the surface deviation increases with operating frequency. In addition, in order to ensure the performance of CATR, it is found that 1/560 of wavelength is the upper limitation for mechanical production. At last, guidance for millimeter wave CATR fabrication is provided.

1. INTRODUCTION

Compact antenna test range (CATR) technology is key to measurement technology of antenna far field pattern and Radar Cross Section of targets [1, 2], the function of which is to convert the spherical wave generated from the feed to quasi-plane wave. The wave is gathered by the reflector, the ripple/taper of amplitude and phase of which should be no more than 1 dB and 10°, respectively. That zone is named as 'quiet zone', because the wave is considered as the uniform plane wave. With the development of microwave technology, the frequency band used increases to millimeter or even sub-millimeter range, which increases the precision requirement for the fabrication of the CATR reflector.

There are several factors that impact the performance of the quiet zone of CATR, such as the truncation of edge, the serration, clutter reflected by rear wall, the leakage of feed, deformation of reflector by gravity, surface deviation and etc. The research of the impact of surface error on parabolic dish antenna is firstly introduced by Ruze [3, 4], in which the relation between random surface error and gain lost is summarized. The model of random surface error and its impact on average power pattern are introduced by Rahmat-Samii et al. [5].

The effect on the far field pattern of antenna catches lots of eyes [6, 7], and yet, the side effect on the near field is not sufficiently studied. Indeed this topic is the key to quiet zone of the millimeter wave CATR. Therefore, in this paper, we study the effects of surface deviation on the near field distribution. According to the study, considerable guidance for further millimeter wave CATR construction is provided.

2. FORMULATION

According to Rayleigh-Sommerfled diffraction integrals [8], propagation of microwave between two parallel planes is:

$$\vec{E} = \frac{1}{4\pi} \int_A \left[\vec{r} \times \left(\hat{n} \times \vec{E}_A \right) (1 + jkr) \frac{e^{-jkr}}{r^3} \right] ds' \tag{1}$$

When z is const, the integral is converted to two-dimension convolution as Equation (2),

$$g(x, y) = \iint f(x', y') h(x - x', y - y', z - z') dx' dy' = f(x, y) * h(x, y) \tag{2}$$

where

$$h(x, y) = (1 + jkr) \frac{e^{-jkr}}{r^3} \tag{3}$$

This algorithm is calculated by Fast Fourier Transform (FFT), which reduces time complexity to $O(N^2 \log_2(N^2))$.

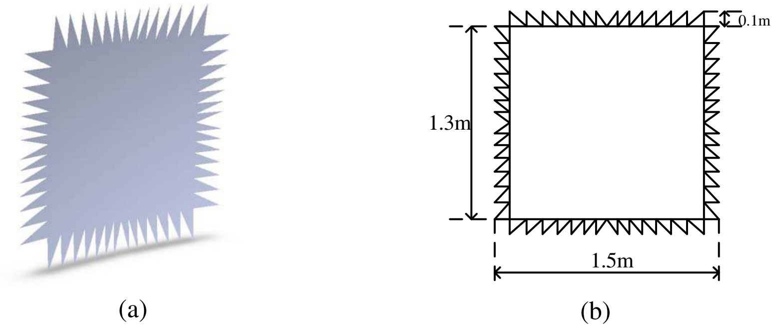


Figure 1: (a) The model of reflector; (b) The normal projection of reflector.

3. SIMULATION AND DISCUSSION

The frequency of millimeter wave CATR ranges from 50 GHz to 200 GHz. It uses a single parabolic reflector, as Figure 1. It is 1.5 m in height and 1.5 m in width, the serration edge of which is 0.1 m, and the focus of which is 2 m. The shape of 'quiet zone' is a cylinder, the diameter of the cross section of which is 0.8 m. The influence of machining precision is investigated.

A PASCAL program is developed based on the formulation given above. The performance of this CATR at 50 GHz to 400 GHz is evaluated. Now the situation of 100 GHz is set as the example.

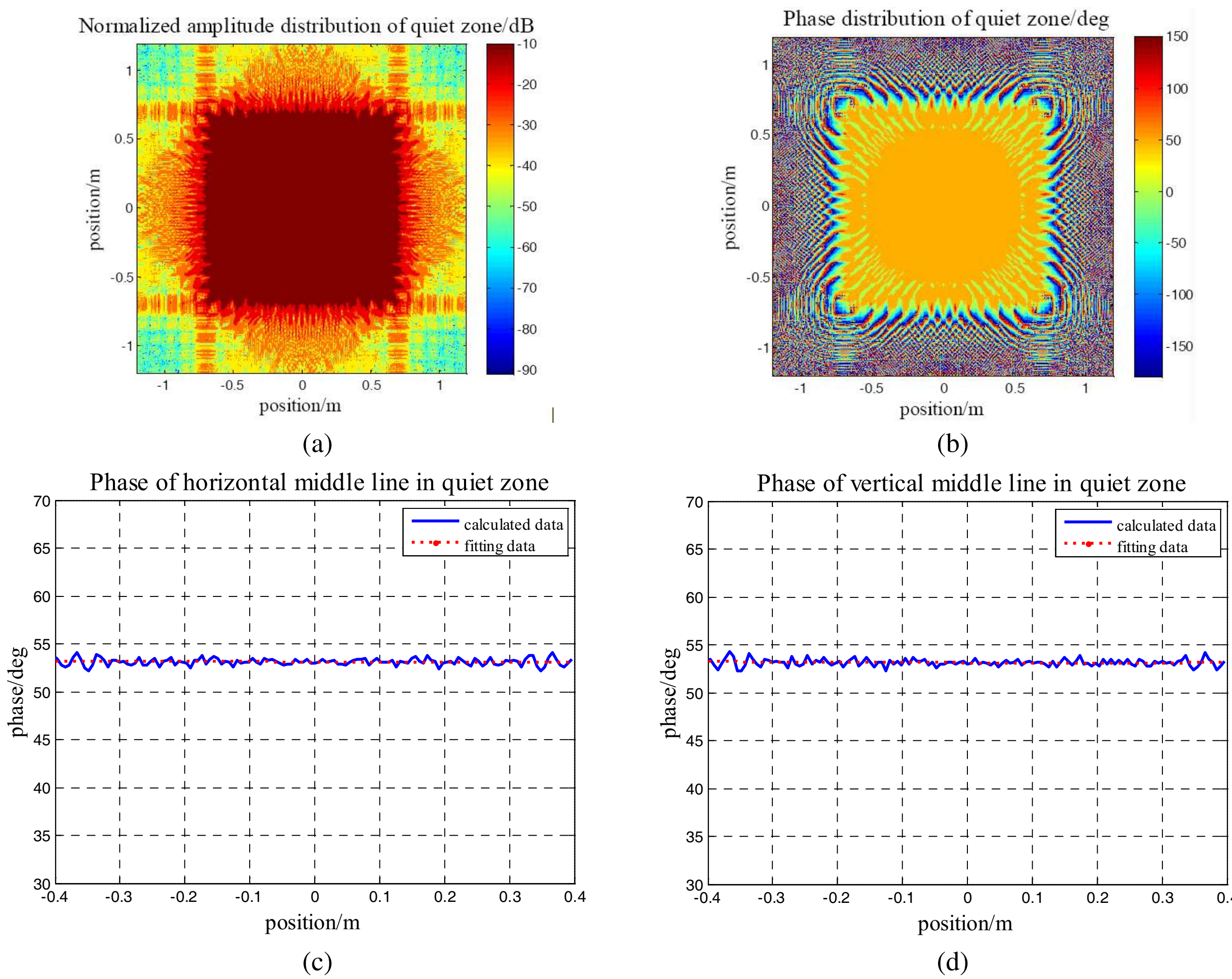


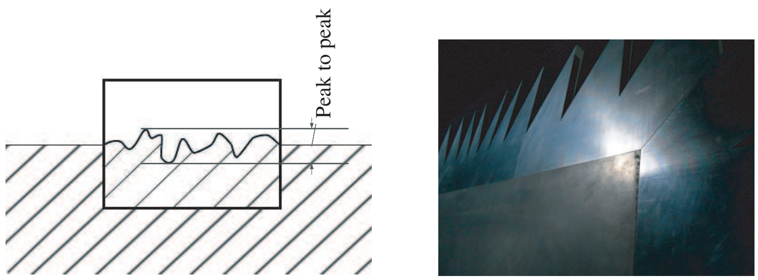
Figure 2: (a) Normalized amplitude distribution of quiet zone; (b) Phase distribution of quiet zone; (c) Phase of horizontal middle line of quiet zone; (d) Phase of vertical middle line in quiet zone.

The taper and ripple of amplitude and phase at 100 GHz are listed in the following table.

Table 1: (a) Taper and ripple of amplitude of quiet zone at 100 GHz; (b) Taper and ripple of phase of quiet zone at 100 GHz.

Result	Horizontal middle line		Vertical middle line	
	Amplitude/dB	Phase/deg	Amplitude/dB	Phase/deg
Taper	0.491	0.054	0.760	0.141
Ripple	0.214	1.908	0.282	2.036

As a matter of fact, the surface of CATR reflector cannot be absolutely smooth even in fine machining. There always is random deviation in the surface of the reflector. According to the current capacity of machining, the random deviation produces limit influence to the quiet zone of normal CATR when operating frequency is no more than 40 GHz.



(a) (b)

Figure 3: (a) Peak to peak value of surface deviation of reflector; (b) Surface deviation of a reflector during manufacture.

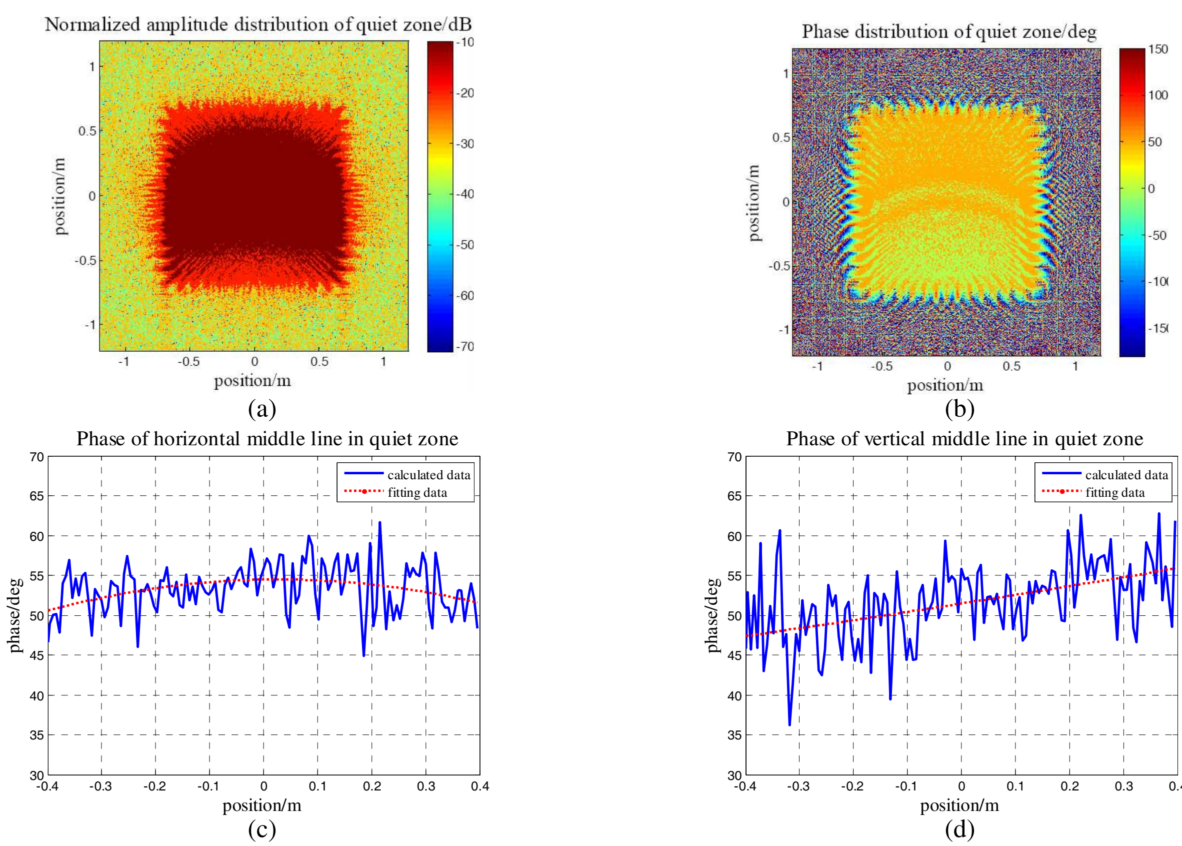
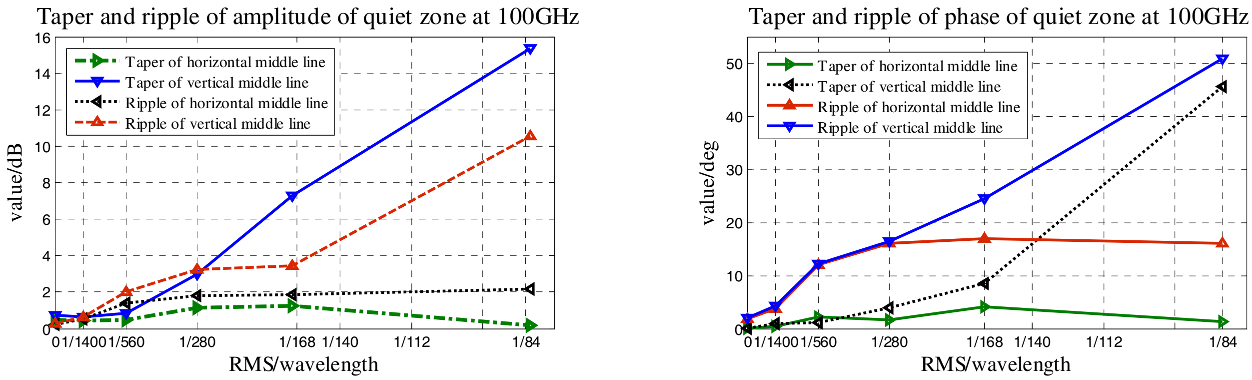


Figure 4: (a) Normalized amplitude distribution of quiet zone; (b) Phase distribution of quiet zone; (c) Horizontal middle line of quiet zone; (d) Vertical middle line in quiet zone.

The surface deviation of reflector is shown in Figure 3(a), which is described by peak to peak value. The surface deviation is clearly seen in the fabricated millimeter wave CATR reflector which needs to be polished before use. When the frequency increases to millimeter waveband, the surface error becomes comparable to the wavelength. So in this situation, the diffraction of undulating on the reflector surface cannot be ignored, and it causes depravation to the performance of quiet zone. To analyze the effects of surface deviation on the quiet zone, five cases of different surface deviation (RMS value) are calculated ($\lambda/84$, $\lambda/168$, $\lambda/280$, $\lambda/560$ and $\lambda/1400$). Here the situation of $\lambda/168$ at 100GHz is set as the example.

The taper and ripple of amplitude and phase are presented in Figure 5.



(a) (b)

Figure 5: (a) Taper and ripple of amplitude of quiet zone at 100 GHz; (b) Taper and ripple of phase of quiet zone at 100 GHz.

From the above figures, when RMS value increases to $\lambda/168$, the ripple of amplitude and phase in quiet zone is not suitable for testing the far field pattern of antenna and the RCS of target. Besides surface deviation causes that the quiet zone is unsymmetrical in vertical direction. Coupling coefficients of different surface deviation at different frequency are presented in Figure 6.

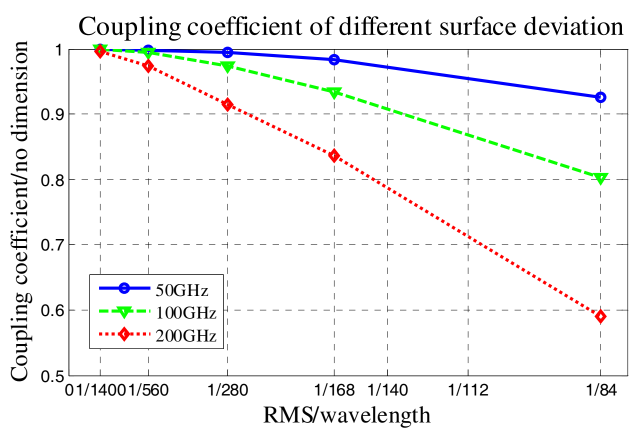


Figure 6: Coupling coefficient of different surface deviation compared to ideal surface.

Due to the result of coupling coefficient and the deterioration of taper and ripple of amplitude and phase, the precision of machining of reflector should be less than $\lambda/560$.

4. CONCLUSIONS

For millimeter wave CATR, the surface deviation exerts an obvious influence to quiet zone. It causes the scatter of energy and results in serious taper and ripple in amplitude and phase. Compared to common CATR operating frequency below 40 GHz, millimeter wave CATR is more sensitive to surface deviation. One hundred of wavelength is upper limitation for mechanical production. There are several lines of research arising from this work which should be pursued. Firstly, the evacuation of energy scatter in quiet zone is to be analyzed. Secondly, the taper and ripple in amplitude and phase of the CATR with or without polish will be test, to verify the calculation above.

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