# Analysis of influence of array plane error on performances of hexagonal phased array antennas

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## Abstract

The electromagnetic performance of phased array antenna (PAA) is degraded because of the array plane structural errors caused by manufacturing processing and assembly. It seriously restrict the realization of high performance of the phased array antenna. Therefore, by introducing the plane structural errors into the antenna pattern function as an additional phase factor, a coupled structural-electromagnetic model is developed, which described the effect on the performance of planar hexagonal phased array antenna with the plane structural errors. Then the direct influence relationship of the electromagnetic performances of antenna with the plane installation accuracy and flatness tolerance are analyzed. The critical value of array plane structural errors is given when meet antenna performance requirement. The analysis results provide a theoretical guidance for engineer to set the reasonable tolerance in manufacturing antenna.

## 1. Introduction

Phased array antenna (PAA) with features of multi-function, high reliability, good stealth performance, high detection and tracking capability, has been widely applied in various radar systems (shown in Fig.1) [1]. With the development of military technology, the requirements for phased array radar system are increasingly high. And the antenna gain, sidelobe level, pointing accuracy etc are closely linked with radar technical indicators. The structural deformations and errors of PAA caused by vibration and impact force, high thermal power, manufacturing processing and assembly etc. can degrade the electromagnetic performances of antenna, for example the gain loss, sidelobe level upgrade and inaccurate beam pointing etc[2]. These deformations severely constrained the achievement of the high performances of PAA, such as the high gain, ultra-low sidelobe. Therefore, it need to study the coupling relationship between the structural errors and electromagnetic performances of PAA, and analyze the influence of the structural errors on the performances of antenna[3].

**Fig. 1 Large land-based PAVE PAWS phased array antenna plane**

Some researchers explored the different influencing factors of antenna electromagnetic performances. Ref [4] studied the effect of the random errors on the performances of phased array antenna based on the probability statistical method. Ref [5] investigated the performances of antenna in the presence of a certain deformation, but did not consider the influence of flatness and installation accuracy of array elements. Ref [6] discussed the effect of array element failure and feed deviation etc on the far-field radiation distribution, but did not consider the structural error factor. Ref [7] studied a coupled three-dimensional flow and thermal model of PAA to the background of engineering design, but only on thermal design and technology. Therefore, the paper developed a coupled structural-electromagnetic model of the planar hexagonal PAA, with the flatness and installation accuracy of array elements regarded as the evaluation standard. The influence of the flatness and installation accuracy on performances of antenna is also analyzed.

## 2. Electromagnetic performance of hexagonal PAA with structural errors

It is assumed that a planar hexagonal PAA locates in the $O-xy$ plane, the total array element of PAA are $M$ oblique columns and $N$ rows, the horizontal interval of the array element is $d_x$, the interval of the row element is $d_y$, the base angle is $\beta$ and the coordinate system is shown in Fig. 2.

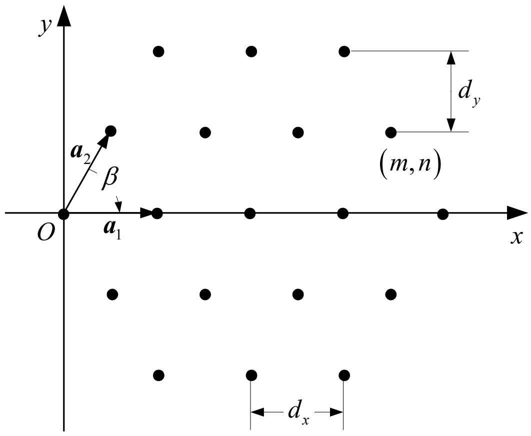



**Fig. 2 The element configuration of planar hexagonal PAA**

$(\theta,\varphi)$ is set as the direction of the target relative to the coordinate system $O\text{-}xyz$, whose direction cosine is $(\cos\alpha_x,\cos\alpha_y,\cos\alpha_z)$. It is known as that the small structural errors of antenna plane only influences the phase of the electrical field of array element without changing the amplitude. Therefore the position deviation of array element can be introduced to the pattern function of the antenna as the additional phase factor. As a result, it is supposed that the position displacement of element $(m,n)$ $(0 \le m \le M-1, 0 \le n \le N-1)$ is $(\Delta x_{mn},\Delta y_{mn},\Delta z_{mn})$.

According to the superposition principle of array antenna, the pattern function of planar hexagonal PAA with plane structural errors can be deduced.

$$E(\theta,\varphi)=\sum_{m=0}^{M-1}\sum_{n=0}^{N-1}E_e I_{mn}\exp\cdot\Big\{jk\Big[\big(mdx+\Delta x_{mn}-\Delta x_{0,0}\big)\cos\alpha_x+\big(ndy+\Delta y_{mn}-\Delta y_{0,0}\big)\frac{\cos\beta}{\sin\beta}\cos\varphi\sin\theta+\big(ndy+\Delta y_{mn}-\Delta y_{0,0}\big)\sin\varphi\sin\theta+\big(\Delta z_{mn}-\Delta z_{0,0}\big)\cos\alpha_z\Big]+j\beta_{mn}\Big\} \tag{1}$$

Where, $E_e$ is the pattern function of the array element, $I_{mn}$ is the amplitude of excitation current and $\beta_{mn}$ is the array phase difference controlled by the phase shifter.

## 3. Analysis of the influence of structural errors

The coupled structural-electromagnetic model is applied to analyze the effect of structural errors on performance of a planar hexagonal PAA as an example to validate. It is assumed that the interval of the array element $d_x$ is $\lambda/2$, the base angle $\beta$ is $60°$.

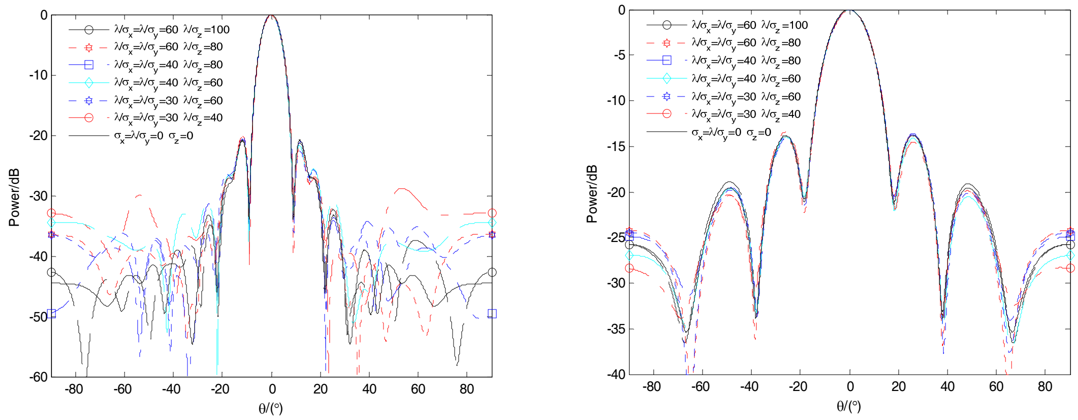
For planar hexagonal PAA, the plane structural errors mainly include flatness and installation accuracy of elements. Among them, the flatness present in $z$ direction and the installation accuracy mainly presents in $x,y$ directions. In this case, the structural error of array plane is similar to adding a normal distribution random error $\Delta x,\Delta y$ which mean value and variance are 0 and $\sigma_x^{\,2}=\sigma_y^{\,2}$ in $x,y$ directions, at the same time, adding a normal distribution random error

**Table 1 The maximum gain loss with different installation accuracy and flatness units:dB**

| Installation accuracy | Flatness | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | $\lambda/200$ | $\lambda/100$ | $\lambda/80$ | $\lambda/60$ | $\lambda/40$ | $\lambda/30$ | $\lambda/20$ | $\lambda/15$ |
| $\lambda/200$ | -0.0051 | -0.0165 | -0.0288 | -0.0476 | -0.1054 | -0.2070 | -0.4750 | -0.6652 |
| $\lambda/100$ | -0.0047 | -0.0158 | -0.0252 | -0.0455 | -0.0943 | -0.2224 | -0.4068 | -0.7607 |
| $\lambda/80$ | -0.0042 | -0.0147 | -0.0267 | -0.0498 | -0.1057 | -0.1881 | -0.4650 | -0.6069 |
| $\lambda/60$ | -0.0048 | -0.0181 | -0.0239 | -0.0370 | -0.0845 | -0.1822 | -0.4702 | -0.7233 |
| $\lambda/40$ | -0.0035 | -0.0184 | -0.0237 | -0.0561 | -0.1112 | -0.1681 | -0.3849 | -0.7368 |
| $\lambda/30$ | -0.0043 | -0.0160 | -0.0276 | -0.0460 | -0.1205 | -0.1933 | -0.4349 | -0.6761 |
| $\lambda/20$ | -0.0041 | -0.0171 | -0.0265 | -0.0549 | -0.0945 | -0.1525 | -0.4094 | -0.7973 |
| $\lambda/15$ | -0.0049 | -0.0161 | -0.0255 | -0.0524 | -0.1156 | -0.1905 | -0.4566 | -0.7450 |

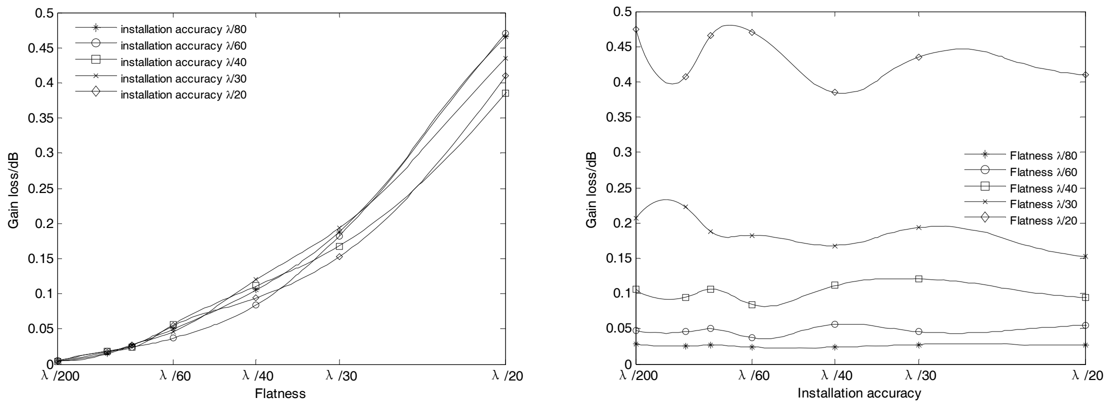
$\Delta z$ which mean value and variance are 0 and $\sigma_z^2$ in $z$ direction.

Through the developed coupling model, the paper calculated the normalized power radiation pattern in $\varphi = 0°$ and $\varphi = 90°$ plane (Seen in Fig. 3), and the maximum gain loss in different flatness and installation accuracy (Listed in Table 1). The curve of the maximum gain loss variation with the flatness and installation accuracy is plotted (Shown in Fig. 4).




**(a) $\varphi = 0°$ plane** **(b) $\varphi = 90°$ plane**

**Fig. 3 Power radiation pattern in different flatness and installation accuracy**




**(a) Horizontal axis is flatness** **(b) Horizontal axis is installation accuracy**

**Fig. 4 The gain loss under different installation accuracy and flatness**

By analyzing the Fig. 3, the conclusions are drowned that: ①The sidelobes of antenna, especially in far-field are seriously affected by the installation accuracy and flatness. Under the combined action of flatness and installation accuracy of array elements, no matter flatness or installation accuracy variation or both at the same time variation, the sidelobe level increased significantly. Therefore, the installation accuracy and flatness is one of the key factors to restrict the realization of the phased array antenna's ultra-low sidelobe performance. ②the influence of the flatness and installation accuracy on the beam pointing and 3dB beam width of antenna is very small, and could be ignored.

Analyzing Fig. 4 and Table 1, it shows that: ③the gain of antenna decreases with increasing flatness and installation accuracy of array plane, similar to an exponential change (Seen in Fig. 4 (a)). For planar hexagonal PAA , when the installation accuracy of array elements and flatness are $\lambda/15$ and $\lambda/20$, respectively, the gain loss is 0.4566 dB($<0.5$ dB). But when the array element's installation accuracy is less than or equal to $\lambda/15$, and the flatness take any values less than or equal to $\lambda/30$, the gain loss are far less than 0.5 dB (Explained in Table 1). ④By comparing Fig. 4(a) and Fig. 4(b), it shows that the flatness has a severe influence on the antenna gain, and the influence of the installation accuracy is relatively small. Therefore, the flatness requirements should be more strict than the installation accuracy of array elements in the practical engineering. ⑤Due to the distribution details of the random errors, the different combination of flatness and installation accuracy can be produced. And the antenna gain loss will also be different, does not conform to the principle that gain loss increases with worse accuracy. That is to say, the aperiodic arrangement of antenna array elements can make the antenna performance better in certain cases.

## 4. Conclusion

For the structural errors of array plane, a coupled structural-electromagnetic model of planar hexagonal PAA is developed. Through analyzing the influence of flatness and installation accuracy of array elements on performance of antenna, the tolerance range of flatness and installation accuracy is obtained when the performance of antenna meet the requirements (gain loss is less than 0.5 dB). According to the calculation results, the influence consequence of flatness and installation accuracy is difference. The flatness has a significant effect on antenna gain, but the influence of installation accuracy on antenna gain is relatively small. Besides, the sidelobes of antenna, especially in far-field are seriously affected by the installation accuracy and flatness. As a result, the structural errors of array plane must be strictly controlled, especially the flatness tolerance. The useful conclusions in the paper can provide the corresponding theoretical guidance for the structural design and reasonable tolerance scheme of PAA.

## 5. Acknowledgements

This research is sponsored by the National Natural Science Foundation of China (Grant No. 51035006, 51205301, 50805111), New Century Excellent Talents in University (Grant No. NCET-09-0633), School Discipline Innovation Talent Recruitment Program (Grant No. B14042), the Specialized Research Fund for the Doctoral Program of Higher Education of China (Grant No. 20120203110012) and the Fundamental Research Funds for the Central Universities (Grant No. K50510040001, K50510040008, 72103389).

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