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# EM ANALYSIS OF PLANAR ELECTRONICALLY SCANNED ARRAY ANTENNAS WITH RADIATING ELEMENT ERRORS

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## Abstract

The analysis of electromagnetic performances of active electronically scanned array antennas (AESA) with distorted plane errors is important to the engineering development of high-performance antennas. An coupled influencing model is developed, which describes the effect on the performances of the errors caused by the bent and bowl shape distortion in the plane element positions. The application of the model to a plane array antenna demonstrates the degradation of the sidelobe level and gain of the antenna with different distortion grades. The satisfactory analysis results provide a theoretical guidance for the engineer to determine the structural tolerance.

***Keywords:*** AESA, radiating element, coupled analysis

## 1. INTRODUCTION

The active electronically scanned array (AESA) technology can satisfy the requirement for high performance and high survival ability, and is also a way to decrease the cost of radar, whose electromagnetic performances and process period have a direct influence on the performance and cost of radar [1-2]. The inaccurate installation of the radiation elements and the height difference of the elements can both trigger the element position errors of AESA. Ref [3] studied the effect of random error on AESA antenna based on the probability statistical method. Ref [4] investigated the distortion error and electromagnetic performance, but only adopted the flatness of array plane as the evaluation standard. Ref [5] discussed the effect of array element failure, and cross and longitudinal feed deviation etc on the far-field radiation distribution, but did not consider the structural error factor. To obtain the relation between the plane distortion and electrical index to provide the significant guidance for the engineer, an influencing model is developed based on the error analysis of all the element positions in bend shape and bowl shape distortion of the plane array.

## 2. ANALYSIS OF DISTORTED AESA

The thermal distribution is not uniform on the plane with center area absorbing more heat than the verge because the irradiation power on array plane is weighted. Therefore, the unequal structural thermal distortion happens in plane of AESA. To accurately analyze the thermal distortion of rectangle plane APA, all the sub-array plane can be divided into the sub-plates of minor size. According to the engineering practice, the general thermal distortion of array plane has two basic forms: the bent shape and bowl shape. In the bent shape distortion, the plane is curled up at both ends, resembling a bent slab. While in the bowl shape distortion, the middle part of plane moves upwards with the four sides remaining unchanged, forming an inverted rectangular bowl.

## 3. EM PERFORMANCE OF DISTORTED AESA

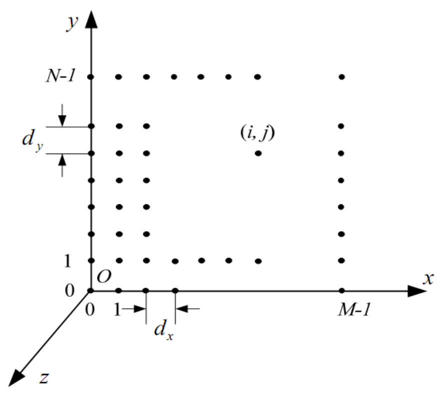



**Fig. 1.** The configuration of rectangle plane AESA.

It is assumed that the radiation elements are assembled with equal interval shown in Fig.1, whose number is $M \times N$ in $O-xy$ . Because the target locates the far field of antenna, the phase difference $\Delta\varphi_x$ can be determined by the optical length difference $\Delta l = d_x \cos\alpha_x$ . $\Delta\varphi_y$ can be decided similarly.

Then, the space phase difference between the $(m,n)$ element and $(1,1)$ element is shown as follows.

$$\Delta\varphi_{mn} = m\Delta\varphi_x + n\Delta\varphi_y \quad (1)$$

$(\theta_0, \phi_0)$ is supposed to be the maximum beam direction whose direction cosine is $(\cos\alpha_{x_0}, \cos\alpha_{y_0}, \ \cos\alpha_{z_0})$. $a_{mn}$ is the weighted coefficient of the amplitude of current of the $(m,n)$ element.

According to the additional phase error of radiation element with the displacement in z direction, the pattern function of AESA with distorted plane error can be deduced.

$$E(\theta,\phi) = \sum_{m=1}^{M}\sum_{n=1}^{N} a_{mn} \exp\{[jkmd_x(\sin\theta\cos\phi - \sin\theta_0\cos\phi_0) + knd_y(\sin\theta\sin\phi - \sin\theta_0\sin\phi_0) + k\cos\theta z_{mn}]\} \quad (2)$$

Where, $z_{mn}$ is the displacement of $(m,n)$ radiation element in z direction.

## 4. Simulation Results and Discussion

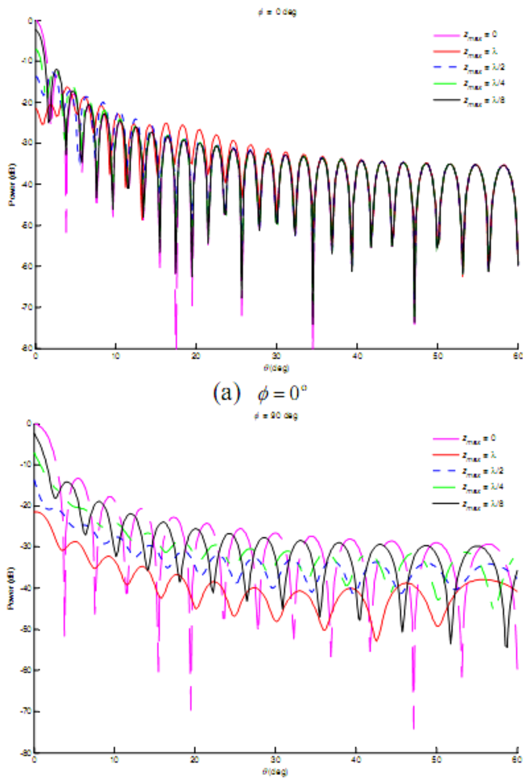
The model is applied to analyze the change in electromagnetic performances with a planar AESA as an example. Table 1 gives the configuration parameters of the antenna. It is assumed that the excited current in the antenna aperture is uniformly distributed.

**Table 1.** Geometry parameters of AESA.

| Length | width | $d_x$ | $d_y$ | $M$ | $N$ |
|---|---|---|---|---|---|
| 29.5λ | 14.5λ | λ 2 | λ 2 | 60 | 30 |

Fig.2 and Fig.3 give the analysis result of antenna under different azimuths, in which the maximum distortion errors of two forms are $0, \lambda, \lambda/2, \lambda/4$ and $\lambda/8$ respectively. By comparing the four radiation patterns, the conclusion can be drawned: (1) Both of the two distortions of the array plane decrease the gain and broaden the main beam. Besides, the same structural distortion has a severe influence on the pattern of the antenna with $\phi = 90^{\circ}$. (2) The sidelobe level of the antenna in main beam region is increased. But the sidelobe shape of the antenna with $\phi = 0^{\circ}$ has no obvious variation. For the same numerical value of the bent shape distortion, the gain-loss of the antenna under two azimuths are the same. That is, with $z_{\max} = 0.5\lambda$, the gain-loss is 5 dB, and with $z_{\max} = 1.0\lambda$, the gain-loss is 10 dB. The bowl shape distortion is the same (3) The bent shape distortion does not change the maximum beam direction. But for the bowl shape distortion of array, the maximum beam direction of antenna with $\phi = 90^{\circ}$ has a small deviation. With $\phi = 0^{\circ}$, the beam direction has no variation. (4) For the bent shape distortion, the distortion values of $\lambda/4$ and $\lambda/8$ do not influence the AESA performances and can be neglected. The distortion value of $\lambda/2$ is considered as the critical value of the antenna structural error with bent shape distortion. (5) For the bowl shape distortion, the distortion value greater than $\lambda/8$ has an obvious effect on the gain and sidelobe of AESA. The performances of the antenna with $\phi = 90^{\circ}$ are subject to the distortion. Therefore, in Fig.4, the situation is analyzed in which the ratio is smaller of the error to wave length of the antenna in the bowl shape distortion, with the corresponding gain-loss and beam deviation presented in Table 2.

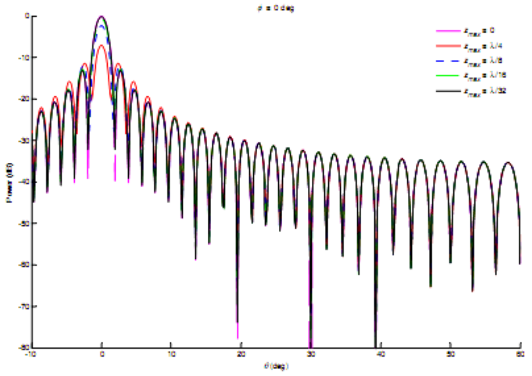
By analyzing Fig.4 and Table 2, the following conclusions are made: (1) For the bowl shape distortion, the value less than $\lambda/16$ of antenna array with $\phi = 0^{\circ}$ can be neglected, while one less than $\lambda/32$ of antenna array with $\phi = 90^{\circ}$ can be not considered. (2) For the same numerical value of the bowl shape distortion and with $\phi = 0^{\circ}$, the gain-loss is obvious but there is no change in the sidelobe level. But the gain of the antenna with $\phi = 90^{\circ}$ has no change while the change in the sidelobe level and beam deviation is obvious.



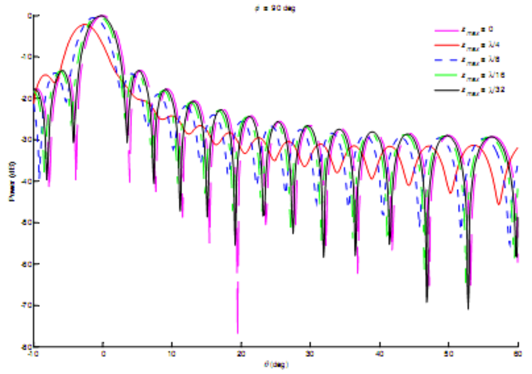
(a) $\phi = 0^{\circ}$

(b) $\phi = 90^{\circ}$

**Fig. 3.** The radiation pattern of AESA with bowl shape distortion.



(a) $\phi = 0^{\circ}$



(b) $\phi = 90^{\circ}$

**Fig. 4.** The radiation pattern of AESA with bowl shape distortion.

**Table 2.** Performances of AESA with bowl shape distortion

| Operation | Gainloss (dB) | | Beam deviation ( $^{\circ}$ ) | |
|---|---|---|---|---|
| | $\phi = 0^{\circ}$ | $\phi = 90^{\circ}$ | $\phi = 0^{\circ}$ | $\phi = 90^{\circ}$ |
| $z_{\max} = \lambda/4$ | -7.36 | -2.79 | 0.3126 | -2.6347 |
| $z_{\max} = \lambda/8$ | -2.42 | -0.54 | 0.3018 | -1.4862 |
| $z_{\max} = \lambda/16$ | -1.01 | 0 | 0.2001 | -0.7027 |
| $z_{\max} = \lambda/32$ | 0 | 0 | 0 | -0.0116 |

## 5. Conclusions

The error of radiation element positions of array plane play a direct influence on the performances of AESA. Therefore, the analysis of electromagnetic performances of rectangle planar AESA with distorted plane errors is important to the engineering development of high-performance antennas. The application of the influencing model to a plane array antenna demonstrates the degradation of the sidelobe level and gain of the antenna with different distortion forms and grades. The requirement of different distortion on the structural error is established. The satisfactory analysis results provide a theoretical guidance for the engineer to determine the structural tolerance.

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