

A Novel Method for Antenna Phase Center Calibration

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Abstract-In many antenna application cases, the phase center is not an important parameter, however, in some special cases, antenna phase center should be measured precisely. In this paper, a novel method for antenna phase center calculation is proposed. The calculation examples validate that this method is efficient and useful for actual engineering application.

I. INTRODUCTION

For an antenna, there are so many parameters to characterize its performances, such as VSWR, gain and axial ratio, etc. In many application cases, the phase center is not an important or critical parameter, however, in some special cases, antenna phase center should be determined precisely and carefully. When an antenna is used as the feed of paraboloid antenna, its phase center should be located in the focus of paraboloid in order to obtain the highest efficiency; If the arrival angle of signal is determined by using interferometer, the phase center of every antenna element need to be determined to measure the length of different base lines; Especially, the phase center of GPS receiver antenna is critical to the location service precision.

In the last years, many literates have studied the antenna phase center calculation or measurement methods. J. Wang and X. Li proposed the method of moving reference point to calculate the phase center of horn antennas[1]. This method can find the phase center for all kinds of antenna, but the calculation or measurement efficiency is low. P. A.J.Misaligned proposed an improved method of moving reference point[2]. In this method, the phase center in one section can be calculated by using three pairs of phase and space angle. This method can determine the phase center fast, but the precision is not so high. In order to improve the precision, the advanced method based on generalized least squares is proposed[3,4]. This method can balance the calculation efficiency and precision, so it is becoming the main method for antenna phase center calculation.

In this paper, a novel method based on generalized least squares for antenna phase center calculation is proposed. In this method, the antenna amplitude and phase pattern are both used to calculate the antenna phase center for better precision; In actual engineering application, the antenna has a working frequency bandwidth, however, the antenna phase center is different at different frequency, so an optimization method for finding a best phase center for the whole bandwidth is also proposed in this paper.

II. PRINCIPLE OF PHASE CENTER CALIBRATION

A. Phase Center Calibration Model

The phase center calibration model is shown as Fig.1. The reference point O is the origin of coordinate system. In actual measurement, the reference point O is the rotation center of rotating floor and the \vec{Z} is the transmitting direction of antenna under test. When the phase center calibration is finished, a new reference point O' called as phased center can be determined. The location vector $\vec{D}(\Delta x, \Delta y, \Delta z)$ is the phase center coordinates referred to point O.

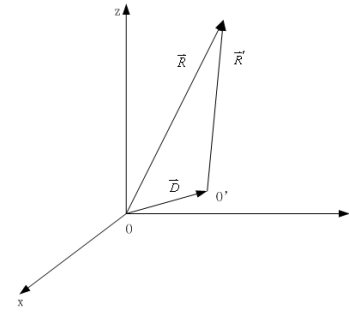


Figure 1. The phase center calibration model.

B. Basic Method of Phase Center Calibration

In the free space, the far field of antenna can be described as following :

$$\vec{E}(\theta, \phi) = \hat{u} E_u(\theta, \phi) e^{j\varphi(\theta, \phi)} e^{-jk \cdot \vec{R}/R} \quad (1)$$

In the equation (1), \hat{u} is the vector of electromagnetic wave polarization. $E(\theta, \phi)$ and $\varphi(\theta, \phi)$ are amplitude and phase pattern respectively. $k = 2\pi/\lambda$ is the wave number. \vec{R} is the distance vector from the reference point O to the observation point. When the reference point is moved to O', antenna far field can be rewritten as equation (2):

$$\vec{E}(\theta, \phi) = \hat{u} E_u(\theta, \phi) e^{-jk \cdot \vec{R}'/R'} e^{j(\varphi(\theta, \phi) - k\vec{R} \cdot \vec{R}')} \quad (2)$$

The phase pattern can be rewritten as

$$\Psi(\theta, \phi) = \varphi(\theta, \phi) - k\vec{R} \cdot \vec{R}' \quad (3)$$

According to the definition of phase center O', the phase pattern $\Psi(\theta, \phi)$ will be a constant. However, the phase pattern can not be a constant in a wide beamwidth for engineering application. There will be an error added on the constant phase pattern, so equation (3) can be expressed as :

$$\Psi(\theta, \phi) = C + \Delta\Psi(\theta, \phi) \quad (4)$$

In order to obtained the constant phase pattern, the $\Delta\Psi(\theta, \phi)$ should be minimal. However, for the most

engineering applications, the far field radiation pattern measured data φ is discrete in θ direction. To express the macroscopic flat level, the phase center calibration problem can be transferred to search a location to minimize the $\Sigma |\Delta\Psi(\theta, \phi)|^2$.

$$\begin{aligned} \text{Min}(\Sigma[\Delta\Psi(\theta, \phi)]^2) &= \text{Min}(\Sigma[\Psi(\theta, \phi) - C]^2) \\ &= \text{Min}(\Sigma[\varphi(\theta, \phi) - k\bar{R} \cdot \bar{R}' - C]^2) \end{aligned} \quad (5)$$

The far field radiation pattern is measured in two orthogonal section such as X-O-Z or Y-O-Z for most engineering applications. In order to solve the phase center location, the generalized least squares is proposed. The two-dimension (2-D) expression of can be deduced as:

$$\begin{aligned} \text{Min}(\Sigma[\Delta\Psi(\theta, \phi)]^2) \\ = \text{Min}\left(\sum_{i=1}^N [\varphi(\theta_i) - k \cdot \Delta t \cdot \sin(\theta_i) + \Delta z \cdot \cos(\theta_i) - C]^2\right) \end{aligned} \quad (6)$$

where Δt is the landscape orientation component of phase center location.

The derivative as following is operated to obtain the minimum of $\Sigma[\Delta\Psi(\theta, \phi)]^2$.

$$\begin{cases} \frac{\partial(\Sigma[\Delta\Psi(\theta, \phi)]^2)}{\partial(\Delta t)} = 0 \\ \frac{\partial(\Sigma[\Delta\Psi(\theta, \phi)]^2)}{\partial(\Delta z)} = 0 \\ \frac{\partial(\Sigma[\Delta\Psi(\theta, \phi)]^2)}{\partial(C)} = 0 \end{cases} \quad (7)$$

The detailed matrix expression of equation (7) can be shown as (8).

$$\begin{bmatrix} k \sum_{i=1}^N \sin^2(\theta_i) & k \sum_{i=1}^N \sin(\theta_i) \cos(\theta_i) & \sum_{i=1}^N \sin(\theta_i) \\ k \sum_{i=1}^N \sin(\theta_i) \cos(\theta_i) & k \sum_{i=1}^N \cos^2(\theta_i) & \sum_{i=1}^N \cos(\theta_i) \\ k \sum_{i=1}^N \sin(\theta_i) & k \sum_{i=1}^N \cos(\theta_i) & N \end{bmatrix} \begin{bmatrix} \Delta t \\ \Delta z \\ C \end{bmatrix} = \begin{bmatrix} \sum_{i=1}^N \varphi(\theta_i) \sin(\theta_i) \\ \sum_{i=1}^N \varphi(\theta_i) \cos(\theta_i) \\ \sum_{i=1}^N \varphi(\theta_i) \end{bmatrix} \quad (8)$$

C. Improved Method of Phase Center Calibration

The basic method of phase center calibration is only used the information of phase. In our opinion, the amplitude information can also be used to improve the calibration precision of phase center. The amplitude pattern represents the power distribution in the space, so the information of strong power direction is more useful than low ones. According to this opinion, the amplitude pattern $E_u(\theta, \phi)$ can be used as the weight factor. Equation (8) is modified as:

$$\begin{bmatrix} k \sum_{i=1}^N E_u(\theta_i) \sin^2(\theta_i) & k \sum_{i=1}^N E_u(\theta_i) \sin(\theta_i) \cos(\theta_i) & \sum_{i=1}^N E_u(\theta_i) \sin(\theta_i) \\ k \sum_{i=1}^N E_u(\theta_i) \sin(\theta_i) \cos(\theta_i) & k \sum_{i=1}^N E_u(\theta_i) \cos^2(\theta_i) & \sum_{i=1}^N E_u(\theta_i) \cos(\theta_i) \\ k \sum_{i=1}^N E_u(\theta_i) \sin(\theta_i) & k \sum_{i=1}^N E_u(\theta_i) \cos(\theta_i) & \sum_{i=1}^N E_u(\theta_i) \end{bmatrix} \begin{bmatrix} \Delta t \\ \Delta z \\ C \end{bmatrix} = \begin{bmatrix} \sum_{i=1}^N E_u(\theta_i) \varphi(\theta_i) \sin(\theta_i) \\ \sum_{i=1}^N E_u(\theta_i) \varphi(\theta_i) \cos(\theta_i) \\ \sum_{i=1}^N E_u(\theta_i) \varphi(\theta_i) \end{bmatrix} \quad (9)$$

D. Optimized Method of Phase Center Calibration

In practical application, arbitrary electronic equipment has a frequency bandwidth. Antenna phase pattern is different vs. frequency, so the phase center is also changed with frequency. Take the feed of paraboloid antenna for example, the focus of paraboloid is stable at all frequencies, and should overlap with the phase center of feed antenna in order to obtain the highest efficiency. Unfortunately, the feed antenna has a changed phase center with frequency. To obtain the better performance in the whole working bandwidth, an optimized phase center should be found. In this paper, the optimization method called as Hooke-Jeeves method is used to find an equivalent phase center in the whole working bandwidth[5]. The initial value of phase center is the average value of high frequency, low frequency and middle frequency.

III. PHASE CENTER CALIBRATION EXAMPLE

A classic horn model which can work at L frequency band is shown in Fig.2. To verify the validity of the calibration method proposed in this paper, two examples are shown: one is the comparison between the basic and improved method, the other is the optimized method used to improve the performance of paraboloid antenna.

The phase patterns calibrated by using basic and improved method are shown in Fig.3. It can be found that the improved method considered the factor of amplitude pattern or power distribution in space can obtain better results obviously.

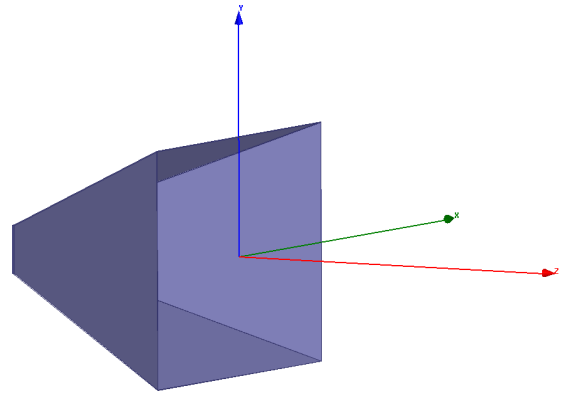


Figure 2. A classic horn model.

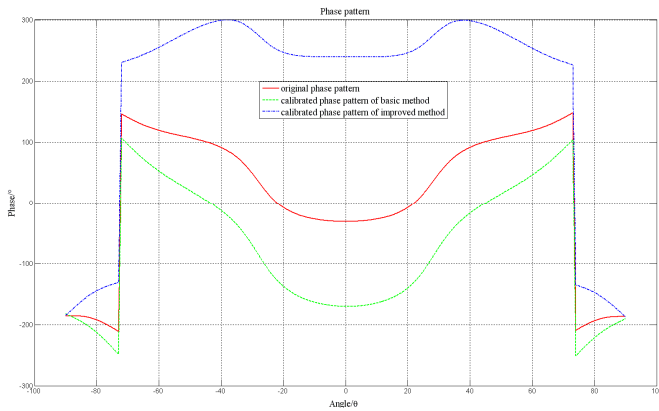


Figure 3. The comparison between the basic and improved method.

An example shown the validity of the optimized method which is used to obtain an equivalent phase center in the whole frequency band will be presented in the meeting in detail. The paraboloid antenna prototype calculated is shown in Fig4. From this example, it can be found that it is important to find an optimized phase center in whole working frequency band in order to improve the performance of paraboloid antenna, especially, for the wideband applications.

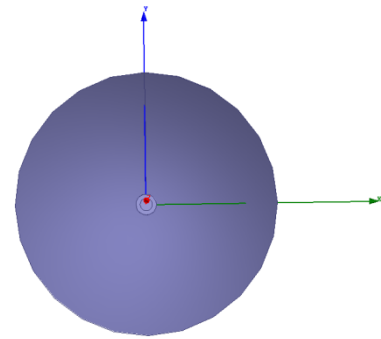


Figure 4. The prototype of paraboloid antenna

IV. CONCLUSIONS

In this paper, a novel method for antenna phase center calibration is proposed. The core of this method is that the position of the phase center should be determined by both antenna amplitude and phase distribution in the space. For the actual engineering applications, all antennas are working at a frequency band and an concept of equivalent phase center is proposed. Two examples have validated the validity of these ideas.

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