Research on Near far field transform algorithm based on probe compensation

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Abstract. In order to solve the problem of sidelobe error caused by probe pattern in current antenna planar near-field and far-field transformation, a new near-field and far-field transform algorithm with probe compensation is studied by combining the advantages of traditional pattern development and edge current approximation method. By measuring the array antenna in a microwave anechoic chamber, the traditional mode expansion method is compared with the hybrid algorithm. The results show that the measurement accuracy of this method is 1.445dB higher than that of the traditional method, and the calculation efficiency is significantly improved, which proves the effectiveness and engineering practicability of this method.

1. Introduction
The planar near-field measurement of antenna is to use the probe with known characteristics to scan in the near-field area to obtain the near-field amplitude and phase data of plane, cylinder or sphere. The measured near-field data are transformed mathematically and the far-field amplitude and phase characteristics of antenna are deduced [1]. Because the measurement probe has a certain size and directivity, its existence will disturb the field to be measured, resulting in that the data after near-field and far-field transformation contains not only the parameter information of the antenna to be measured, but also the parameter information of the sampling probe [2]. In order to obtain more accurate measurement results, only when the characteristics of the probe are known accurately, it is possible to compensate the influence of the probe.

At present, the main lobe measurement effect of antenna pattern is good, and the error of side lobe is mainly related to probe compensation. The E-plane pattern of the probe has been proved to be very close to the actual measured value, while the more approximate formula for the H-plane pattern has been under study [3]. At present, there are mainly two methods of H-plane pattern used in near-field and far-field transformation in China: Stratton Chu integration method and E-plane electric field method. The former introduces large errors in the whole sidelobe region due to ignoring some important components, while the latter mainly introduces large errors in the far region [4].

In order to get more accurate antenna pattern, a new algorithm is proposed by combining the advantages of E-plane electric field method and edge current approximation method. Combining the new probe compensation algorithm with the traditional algorithm, a hybrid algorithm is proposed to...
calculate the antenna pattern. The advantages of this method are that the calculation formula is relatively simple, the precision is high and the efficiency is high. The experiment shows that it can improve the accuracy and efficiency.

2. Near far field transformation with probe compensation

In order to accurately deduce the near-field and far-field characteristics of the antenna from the measured data, the influence of the probe should be eliminated in the calculation. Therefore, it is necessary to establish the coupling equation between the antenna and the probe, that is, to find out the relationship between the ratio of the received signal of the probe to the input signal of the antenna to be tested and the characteristics and mutual positions of the two antennas.

![Position relationship between antenna and probe](image)

Figure 1. Position relationship between antenna and probe

The coupling equation can be deduced by reciprocity theorem. The schematic diagram is shown in Figure 1, $S_0$ is the antenna to be tested and $S_0'$ is the test probe. According to the coupling equation, the energy received by the probe can be obtained by omitting the constant scale factor [5]:

$$
\frac{b_0'(x_0, y_0, d)}{a_0} = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} A(\vec{k}) \cdot \frac{k_z}{k} A\left(\frac{\vec{k}}{k}\right) e^{-i\vec{k} \cdot \vec{d}} dk_x dk_y
$$

(1)

In the formula, $\frac{b_0'(x_0, y_0, d)}{a_0}$ is the quantity obtained by measurement, $A(\vec{k})$ is the plane wave of the probe in its own coordinate system, $A\left(\frac{\vec{k}}{k}\right)$ is the plane wave spectrum of the antenna in its own coordinate system, $k$ is the wave number, $k_z = k \cos \theta, \vec{k} = k_x \hat{x} + k_y \hat{y} + k_z \hat{z}$.

Finally, the probe pattern function is [6]:

$$
F_{E}(\theta, \varphi) = \frac{\cos \theta}{f_E(\theta)} \left[ D'(\theta, \varphi) \cos \varphi + D''(\theta, \varphi) \sin \varphi \right]
$$

(2)

$$
F_{H}(\theta, \varphi) = \frac{\cos \theta}{f_H(\theta)} \left[ D''(\theta, \varphi) \cos \varphi - D'(\theta, \varphi) \sin \varphi \right]
$$

(3)

In the formula, $b_0'(x, y, d)$ and $b_0'(x, y, d)$ are the two orthogonal polarizations of the probe, $D'(\theta, \varphi)$ and $D''(\theta, \varphi)$ are the normalized E-plane pattern function of the probe, $f_E(\theta)$ is the normalized E-plane pattern function of the probe, the wavelength is $\lambda$.

At present, it is necessary to make $f_H(\theta)$ more accurate in order to better compensate the influence of the probe in the test.
3. Hybrid algorithm

3.1. E-surface electric field method

The so-called E-plane electric field method is to obtain the H-plane pattern function by integrating the known E-plane direction function of the probe. The specific formula of e-surface electric field method is [7]:

$$
\mathbf{E}(r \to \infty, \theta, \phi = 0)_{0 \leq \theta \leq \pi / 2} = \frac{e^{i kr}}{kr} \frac{k^2}{2\pi} \hat{e}_x \times \int_0^\infty \int_{-\infty}^\infty \mathbf{E} \left( \mathbf{R} \right) e^{-ikr' \sin \theta} dx' dy'
$$

In the formula, \( \mathbf{R} = x'e_x + y'e_y \) represents the integral vector from the origin to the area factor \( dx'dy' \) in the integral plane. The electric field and magnetic field of TE10 mode are respectively:

$$
\mathbf{E}_{10} = E_0 (1 + \Gamma) \cos \left( \frac{\pi x}{a} \right) \hat{e}_y
$$

$$
\mathbf{H}_{10} = -\frac{E_0}{Z_0} \left[ (1 - \Gamma) \frac{\beta}{k} \cos \left( \frac{\pi x}{a} \right) \hat{e}_x + \frac{\pi}{ika} \sin \left( \frac{\pi x}{a} \right) \hat{e}_z \right]
$$

Here, \( E_0 \) is the amplitude of TE10 mode. By simplifying formula (4) and formula (5), the H-plane pattern function of the probe can be obtained [8]:

$$
f_h(\theta) = \cos \theta \left( \frac{a \sin \theta}{\lambda} \right) \left( 1 - \frac{2a \sin \theta}{\lambda} \right)^2
$$

In the E-plane electric field method, the E-plane pattern function of the probe is as follows:

$$
f_e(\theta) = \frac{1 + \sqrt{1 - \left( \frac{\lambda}{2a} \right)^2} \cos \theta \sin \left( \frac{b\pi}{\lambda} \sin \theta \right)}{1 + \sqrt{1 - \left( \frac{\lambda}{2a} \right)^2} \frac{b\pi}{\lambda} \sin \theta}
$$

\( \lambda \) is the wavelength, and \( \theta \) is the angle between the Z-axis and the line connecting any point in space and the origin (0, 0) in the coordinate system.

3.2. Edge current method

For the study of H-plane pattern, foreign emissary Risser proposed Stratton Chu integration method, which eliminates the influence of probe edge current. The formula is [9]:

$$
f_H(\theta) = A_H \frac{[\cos (\beta + \beta / k) + \Gamma (\cos \theta - \beta / k)]}{\left[ \frac{\pi}{2} \right]^2 - \left( \frac{ka}{2} \sin \theta \right)^2} \sin \left( \frac{ka}{2} \sin \theta \right)
$$

In the formula, \( AH = \frac{-ikabE_0}{8} \), \( E_0 \) is the amplitude of TE10 mode and \( \Gamma \) is the reflection coefficient of the probe; \( \frac{\beta}{k} = \sqrt{1 - \left( \frac{\lambda}{2a} \right)^2} \).

Edge current method is a method based on edge current diffraction theory [10]. The essence is based on the Stratton Chu integral method, plus the edge current. Thus, the formula of edge current can be obtained.
$$f_H(\theta) = A_H \left[ \frac{\cos \theta + \beta / k + \Gamma(\cos \theta - \beta / k)}{\left(\pi / 2\right)^2 - (ka \sin \theta / 2)^2} + C_0 \right] \cdot \cos \left( \frac{ka}{2} \sin \theta \right)$$  \hspace{1cm} (10)

### 3.3. Hybrid algorithm

The E-plane electric field method and edge current method are measured, and the results are compared with the simulation results of HFSS software. The results are shown in Figure 2. It can be seen from Figure 2 that in a certain range, the E-plane electric field method is closer to the simulation data; in the far region, the edge current method considers the influence of edge current, and the data is closer to the simulation data. By combining the two algorithms, a more accurate antenna near-field and far-field transform algorithm can be obtained.

The E-plane electric field method is used in the range of \((-68^\circ, 68^\circ)\), and the edge current method is used in the range of \((-68^\circ, 90^\circ)\) and \((-90^\circ, -68^\circ)\). The hybrid algorithm is based on H-plane.

The formula of hybrid algorithm is as follows:

$$f_H(\theta) = \begin{cases} 
\cos \theta^* \cos \left( \frac{\pi a}{\lambda} \sin \theta \right) / \left[ 1 \left( \frac{2a}{\lambda} \sin \theta \right)^2 \right] & -68^\circ \leq \theta \leq 68^\circ \\
A_H \left[ \cos(\theta + \beta / k) + \Gamma(\cos \theta - \beta / k) \right]
\left( \frac{\pi}{2} \right)^2 - \left( \frac{ka}{2} \sin \theta \right)^2 \\
+ C_0 \right] \cdot \cos \left( \frac{ka}{2} \sin \theta \right) & \theta < -68^\circ \text{ or } \theta > -68^\circ
\end{cases}$$  \hspace{1cm} (11)

### 4. Result analysis

The complete antenna pattern can be obtained by introducing the probe formula into the near-field and far-field transformation formulas (2) and (3) with probe compensation. By subtracting the pattern of the calculation curve and the simulation curve, the error curve of the pattern outside the main lobe area is obtained, and the root mean square of the error curve is calculated. In this paper, the root mean square (RMS) of the ESS / SIG (error signal ratio) of all points in the pattern is obtained by using the
global analysis method. RMS corresponds to the standard deviation in the normal distribution. Because we mainly analyze the influence of various methods on the side lobe, we only analyze the error of the side lobe region.

The global analysis method is used in error calculation. Firstly, the error of the whole pattern is calculated, and the error of the pattern is obtained by subtracting the result curve of the hybrid algorithm from the simulation curve, and then the root mean square of the error curve is calculated. Then the side lobe uncertainty is calculated. The sidelobe uncertainty can be calculated according to the following formula: uncertainty (DB) = 20 * log\left(1 + 10^{\frac{\text{RMS} - \text{C} - \text{SLL}}{20}}\right). Where SLL = sidelobe level to be analyzed (DB). Here, C is zero. The formula of error to signal ratio (s/N) calculated from uncertainty is: \(\frac{\text{error identification}}{\text{signal ratio}}\) = 20 * log\left(1 - 10^{\frac{\text{uncertainty}}{20}}\right). Since the calculation of uncertainty mainly analyzes the far side lobe, SLL is taken as -19dB to calculate the first low side lobe error.

The experimental results are shown in Table 1:

|                      | RMS/dB   | uncertainty/dB | ESS/SIG/dB |
|----------------------|----------|----------------|------------|
| E-surface electric   | 11.415   | ±3.0310        | -10.6160   |
| field method         |          |                |            |
| Edge current method  | 9.4933   | ±2.5077        | -12.0145   |
| Hybrid algorithm     | 5.0346   | ±1.5859        | -15.5516   |

5. Conclusion
Through the analysis of root mean square, it can be seen that the root mean square of the hybrid algorithm is lower than other algorithms, that is, compared with other algorithms, the hybrid algorithm is more stable and accurate. From the uncertainty and error signal ratio, it can be seen that the hybrid algorithm has a higher accuracy of -19dB sidelobe, which is 1.4454dB higher than the E-plane electric field method and 0.9218dB higher than the edge current method. Therefore, the hybrid algorithm has good usability in the near and far regions of the antenna, the accuracy has been significantly improved, and the computational efficiency has been improved to a certain extent.

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