Investigation of Probe Correction Technique in Planar Near-Field Antenna Measurements

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Abstract — **Probe correction techniques in near-field theory are investigated theoretically. Simplified probe correction is proposed for the case of good crosspolarization isolation of the probe pattern and angles not far from the boresight of the antenna pattern, which leads to significant reduction of computational effort for obtaining of the far-field radiation pattern of the antenna under test. For the proposed simplified probe correction phase data of the far-field radiation pattern of the probe is not required, which additionally makes it attractive for implementation.**

Keywords — **Near-field measurements, probe correction, planar wave spectrum**

I. Introduction

Modern planar scanning techniques in near-field measurements of antennas are based on planar-wave spectrum (PWS) representation of the fields which could be found in [3], [4]. There is a simple relationship between PWS of the antenna and its far field pattern [3], [4]. This relationship adds significant practical importance of such representation of the fields and particularly to the planar near-field antenna measurements.

During the last quarter century, the advent of the fast Fourier transform (FFT) technique [2] , as well as the rapid progress in electronics, signal processing, and computers, made the planar-scanning near-field measurement increasingly fast, accurate, and economical. As a result, activities in near-field measurement on planar surfaces proliferated [3]-[4], beginning with the probe-correction technique proposed by Kerns [1]. A comprehensive review of this subject was recently conducted by Yaghjian [3].

The problem with the probe correction is as follows. If the pattern of the measuring probe were isotropic the probe wouldn't have influenced the measurement result. Because there are not isotropic probes the last always influence the measurement and has to be considered in the computation. Consideration of the directional properties of the probes used in planar near-field antenna measurements leads to significant complication of computational effort.

This paper emphasizes on PWS representation of the fields and probe correction that has to be applied in planar near-field antenna measurements. Simplified probe correction procedure is proposed, which could save significant amount in computational effort in near-far field transformation.

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The proposed simplified probe correction is applicable in the case of good cross polarization isolation of the probe pattern (example is a open ended rectangular waveguide used as a probe) and for the tilt angles around 30 degrees far from boresight of the antenna pattern.

II. Formulation of Antenna Near fields and Probe Correction Technique

In a source-free free-space region, in which near fields are measured, the time-harmonic Maxwell equations can be transformed into the following vector wave equations:

$$\begin{aligned} &\nabla^2 \vec{E} + k^2 . \vec{E} = 0 \\ &\nabla^2 \vec{H} + k^2 . \vec{H} = 0 \\ &\vec{\nabla} . \vec{E} = \vec{\nabla} . \vec{H} = 0 \end{aligned} \qquad (1)$$

It can be shown that following expressions constitute a solution of the equations (1) for $z \geq 0$ and satisfy the prescribed boundary conditions on the plane $z = 0$:

$$\begin{aligned} \vec{E}(x,y,z) &= \frac{1}{2\pi} \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} \vec{A}(k_x, k_y) e^{-j\vec{k}\vec{r}} dk_x dk_y \\ \vec{H}(x,y,z) &= \frac{1}{2\pi} \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} \vec{k} \times \vec{A}(k_x, k_y) e^{-j\vec{k}\vec{r}} dk_x dk_y \end{aligned} \qquad (2)$$

In the equation (2) $\vec{k}$ is the wave vector with the components along the three coordinate axes and $\vec{r}$ is the position radius-vector as follows:

$$\begin{aligned} \vec{k} &= k_x . \vec{i}_x + k_y . \vec{i}_y + k_z . \vec{i}_z \\ k^2 &= \vec{k} . \vec{k} \end{aligned} \qquad (3)$$

$$\vec{r} = x . \vec{i}_x + y . \vec{i}_y + z . \vec{i}_z \qquad (4)$$

Vector $\vec{A}$ represents planar wave spectrum of the field because the expression

$$\vec{A}(k_x,k_y).e^{j\vec{k}.\vec{r}} \qquad (5)$$

represents a uniform plane wave propagating in the direction $\vec{k}$. There is a relationship between the tree components of the PWS so that knowing A_x and A_y is enough for determining all the tree components of the PWS:

$$k_x A_x(k_x,k_y)+k_y A_y(k_x,k_y)+k_z A_z(k_x,k_y)=0 \quad (6)$$

In planar near-field measurements, the antenna is placed in the plane $z=0$, as shown on Figure 1. Planar scanning is conducted in the plane $z=z_t$, near the antenna.

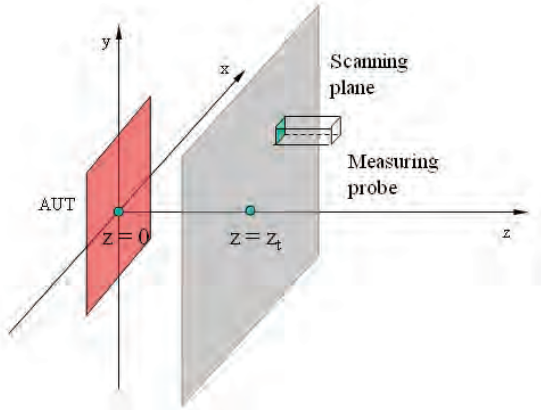

Figure 1: Setup of planar near-field measurement

The radiation condition requires that for $z \geq 0$ the following relations between components of the wave vector should be satisfied [4]:

$$k_z=\begin{cases}\sqrt{k^2-k_x^2-k_y^2}; k_x^2+k_y^2 \leq k^2 \\ -j\sqrt{k_x^2+k_y^2-k^2}; k_x^2+k_y^2 \geq k^2\end{cases} \qquad (7)$$

An imaginary k corresponds to an evanescent PWs, which is rapidly attenuated away from the plane $z=0$.

In the plane $z=z_t$ the x, y components of the field using (2) can be expressed as:

$$E_x(x,y,z_t)=\frac{1}{2\pi}\int_{-\infty}^{\infty}\int_{-\infty}^{\infty}A_x(k_x,k_y)e^{-jk_z z_t}.e^{-j(k_x x+k_y y)}.dk_x dk_y$$
$$E_y(x,y,z_t)=\frac{1}{2\pi}\int_{-\infty}^{\infty}\int_{-\infty}^{\infty}A_y(k_x,k_y)e^{-jk_z z_t}.e^{-j(k_x x+k_y y)}.dk_x dk_y \qquad (8)$$

we concentrate only in x, y components because z component is easily determined from (1) and (6). Because of the influence of the measuring probe direct measurement of $E_x(x,y,z_t)$ and $E_y(x,y,z_t)$ is not possible. What is actually measured in the plane $z=z_t$ is the reaction of the probe:

$$b_1(x,y,z_t)= \frac{1}{2\pi}\int_{-\infty}^{\infty}\int_{-\infty}^{\infty}\vec{R}^{b_1}(k_x,k_y).\vec{A}(k_x,k_y)e^{-jk_z z_t}.e^{-j(k_x x+k_y y)}.dk_x dk_y \qquad (9)$$

Where $\vec{R}^{b_1}(k_x,k_y)$ is the "in advance" known pattern of the probe with representation in spherical and cartesian coordinate system respectively:

$$\vec{R}^{b_1}(k_x,k_y)=R_\theta^{b_1}(k_x,k_y).\vec{i}_\theta+R_\varphi^{b_1}(k_x,k_y).\vec{i}_\varphi \qquad (10)$$

$$\vec{R}^{b_1}(k_x,k_y)= R_x^{b_1}(k_x,k_y).\vec{i}_x+R_y^{b_1}(k_x,k_y).\vec{i}_y+R_z^{b_1}(k_x,k_y).\vec{i}_z \qquad (11)$$

Because of the planar scanning we may choose Cartesian representation and rewrite equation (9) in the form:

$$b_1(x,y,z_t)= \frac{1}{2\pi}\int_{-\infty}^{\infty}\int_{-\infty}^{\infty}\left(R_x^{b_1}.A_x+R_y^{b_1}.A_y+R_z^{b_1}.A_z\right). e^{-jk_z z_t}.e^{-j(k_x x+k_y y)}.dk_x dk_y \qquad (12)$$

Equation (12) is inverse Fourier transform of the scalar product with respect to k_x and k_y. We could obtain the scalar product applying Fourier transform of the measured reaction of the probe and multiplying with the constant $e^{jk_z z_t}$:

$$R_x^{b_1}.A_x+R_y^{b_1}.A_y+R_z^{b_1}.A_z = e^{jk_z z_t}.\frac{1}{2\pi}\int_{-\infty}^{\infty}\int_{-\infty}^{\infty}b_1(x,y,z_t).e^{j(k_x x+k_y y)}.dk_x dk_y \qquad (13)$$

Now taking into account equation (6) we can obtain A_z knowing A_x, A_y and rewrite equation (13) in the form:

$$A_z=-\frac{k_x}{k_z}A_x-\frac{k_y}{k_z}A_y \quad (14)$$

$$\left(R_x^{b_1}-\frac{k_x}{k_z}R_z^{b_1}\right).A_x+\left(R_y^{b_1}-\frac{k_y}{k_z}R_z^{b_1}\right).A_y = e^{jk_z z_t}.\frac{1}{2\pi}\int_{-\infty}^{\infty}\int_{-\infty}^{\infty}b_1(x,y,z_t).e^{j(k_x x+k_y y)}.dk_x dk_y \qquad (15)$$

Equation (15) is used for obtaining A_x, A_y of the PWS of the antenna under test. Since there is two unknowns another equation is needed, which could be obtained in the same way as equation (15), but using second probe (with different

pattern) or the same probe but 90 degrees rotated. If $\vec{R}^{b_2}(k_x, k_y)$ denotes pattern of the second probe the same equation as (15) is valid:

$$\left(R_x^{b_2} - \frac{k_x}{k_z} R_z^{b_2}\right).A_x + \left(R_y^{b_2} - \frac{k_y}{k_z} R_z^{b_2}\right).A_y = e^{jk_z z_t}.\frac{1}{2\pi}\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} b_2(x, y, z_t).e^{j(k_x x + k_y y)}.dk_x dk_y \quad (16)$$

Equations (15) and (16) are used for determining of A_x, A_y components of the PWS. The solution is given by the following equations:

$$P_{b_1} = e^{jk_z z_t}.\frac{1}{2\pi}\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} b_1(x, y, z_t).e^{j(k_x x + k_y y)}.dk_x dk_y$$
$$P_{b_2} = e^{jk_z z_t}.\frac{1}{2\pi}\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} b_2(x, y, z_t).e^{j(k_x x + k_y y)}.dk_x dk_y \quad (17)$$

$$\Delta_x = \begin{vmatrix} P_{b_1}; \left(R_y^{b_1} - \frac{k_y}{k_z} R_z^{b_1}\right) \\ P_{b_2}; \left(R_y^{b_2} - \frac{k_y}{k_z} R_z^{b_2}\right) \end{vmatrix}$$

$$\Delta_y = \begin{vmatrix} \left(R_x^{b_1} - \frac{k_x}{k_z} R_z^{b_1}\right); P_{b_1} \\ \left(R_x^{b_2} - \frac{k_x}{k_z} R_z^{b_2}\right); P_{b_2} \end{vmatrix} \quad (18)$$

$$\Delta = \begin{vmatrix} \left(R_x^{b_1} - \frac{k_x}{k_z} R_z^{b_1}\right); \left(R_y^{b_1} - \frac{k_y}{k_z} R_z^{b_1}\right) \\ \left(R_x^{b_2} - \frac{k_x}{k_z} R_z^{b_2}\right); \left(R_y^{b_2} - \frac{k_y}{k_z} R_z^{b_2}\right) \end{vmatrix}$$

$$A_x = \frac{\Delta_x}{\Delta}; A_y = \frac{\Delta_y}{\Delta}$$

III. Simplified Probe Correction

Procedure for obtaining of the components A_x, A_y of the PWS of the antenna under test described with equations (17), (18) is common one. In actual measurement discretization of the plane in front of the antenna under test (AUT) is performed and integrals (17) are solved with the help of Discrete Fourier Transform (DFT). Sometimes procedure given with (17) and (18) is too complicated, because for each point of the discretized plane three determinants should be solved (Δ_x, Δ_y and Δ). This makes the speed of the computation very slow and if processing of hundreds of antenna beams is needed the computation time may take hours even on good speed PCs.

The procedure given with equations (17) and (18) could be further simplified if crosspolarized component of the probe pattern is negligible. For linear polarized probes this constitutes the following:

$$R_y^{b_1} \approx 0$$
$$R_x^{b_2} \approx 0 \quad (19)$$

Equations (19) says that $\vec{R}^{b_1}$ is polarized along x axes and $\vec{R}^{b_2}$ is polarized along y axes. Also for angles not very far from the AUT boresight z components of the probe patterns could be considered zero:

$$R_z^{b_1} \approx 0$$
$$R_z^{b_2} \approx 0 \quad (20)$$

Taking into account (19) and (20) equations (15) and (16) could be expressed in a simplified form:

$$R_x^{b_1}.A_x = e^{jk_z z_t}.\frac{1}{2\pi}\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} b_1(x, y, z_t).e^{j(k_x x + k_y y)}.dk_x dk_y$$
$$R_y^{b_2}.A_y = e^{jk_z z_t}.\frac{1}{2\pi}\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} b_2(x, y, z_t).e^{j(k_x x + k_y y)}.dk_x dk_y \quad (21)$$

If the same probe is used for the measurement but 90 degrees rotated for each scan the simplified solution for the PWS of the antenna could be write using (21):

$$A_x = \frac{1}{R}.e^{jk_z z_t}.\frac{1}{2\pi}\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} b_1(x, y, z_t).e^{j(k_x x + k_y y)}.dk_x dk_y$$
$$A_y = \frac{1}{R}.e^{jk_z z_t}.\frac{1}{2\pi}\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} b_2(x, y, z_t).e^{j(k_x x + k_y y)}.dk_x dk_y \quad (22)$$

where R is the pattern of the probe for the dominant polarization. If circular polarized probes are used equation (22) takes similar form for the two orthogonal circular polarized components of the PWS A_{LHCP} and A_{RHCP}:

$$A_{LHCP} = \frac{1}{R_{LHCP}}.e^{jk_z z_t}.\frac{1}{2\pi}\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} b_1(x,y,z_t).e^{j(k_x x+k_y y)}.dk_x dk_y$$

$$A_{RHCP} = \frac{1}{R_{RHCP}}.e^{jk_z z_t}.\frac{1}{2\pi}\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} b_2(x,y,z_t).e^{j(k_x x+k_y y)}.dk_x dk_y \quad (23)$$

where R_{LHCP} and R_{RHCP} are the patterns of the measuring probe for the two orthogonal linear polarizations.

IV. Discussion and Conclusion

In this paper common case of probe correction in planar near field antenna measurements was investigated and revised. A simplified probe correction was proposed for the case of good crosspolarization of the probe pattern and angles not far from the boresight of the antenna under test. The proposed simplified procedure for probe correction leads to significant reduction of the computational effort for calculation of the planar wave spectrum of the antenna, which makes it attractive for implementation.

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