

Error Estimation of Three Dipoles used as near Field sensors

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Abstract: Three sensors coupled in a crossed configuration are used as near field calculating unit of a transmitter in an unbounded ground plane. The Method of Moments is applied to calculate approximately the inaccuracy produced by the measuring unit in the near field. The Probe measures both co-pole, cross-pole and z-directed dipole components simultaneously. However, due to multiple reflections between the radiator and dipoles, near field values are changed. Computation was carried out for the calibration of the probe and to test the co-pole voltage and field (with no probe) in x-y plane at 10GHz to compare the relative tested co-pole voltage pattern with the relative tested field pattern (with no measuring unit). Since the relative tested co-pole voltage and field are analyzed, no inaccuracy is forced at the midpoint of the plane.

Keywords – Basis Functions; Co-pole; Cross pole; EM wave; MoM; Waveguides.

1. INTRODUCTION

The opening of waveguide in an unbounded ground plane supplied by a waveguide being taken as a transmitter is considered as energized in the TE₁₀ condition. The three dipoles i.e. along y-axis (co-pole), along x-axis (cross-pole) and dipole in z-axis are connected in crossed structure are considered as a near-field estimating unit. These sensors are delicate to electric field slanting alongside the axis of the y-axis, x-axis and z-directed dipole of the sensor. The scattering characteristics of the elements are polarization oriented. The method of moments approach is applied to resolve boundary value problems. The waveguide opening field is designated by the weighted sinusoidal global basis functions, and currents over co-pole, crossed pole and z-axis directed dipole are designated by pulse basis functions. The boundary conditions at the opening is forced at the same time on the plane of a waveguide opening and on the axis of co-pole, cross pole and z-axis directed dipole by considering multiple reflections and mutual coupling automatically.

Estimation has been done for the calibration of the measuring unit and to test the relative co-pole voltage pattern to the relative electric field (without probe) pattern, and inaccuracy produced by the sensors is evaluated.

Several researchers used many methodologies such as the variational, correlation matrix, and integral equation methods [1], [2]. The number of approaches has been evolved for the calculation of the mutual and self-admittance between radiating elements [2], [3]. Various authors used the method of moment procedure to work out the waveguide [3], [4], [5]. MoM investigation of

waveguide transmitter and dipole, crossed dipole as the near field measuring unit is given by writer [8], [9].

II. PROBLEM FORMULATION

The three dipoles i.e. along y-axis (co-pole), along x-axis (cross-pole) and along z-axis in the near field of waveguide transmitter opening is illustrated in Figure 1.

The magnetic field at the opening is given by:

$$H_x^{inc1} = -Y_0 \cos\left(\frac{\pi x}{2a}\right) e^{-j\beta z} \quad [1]$$

The current on the y-axis dipole is designated by [8]:

$$I = \hat{u}_y \sum_{p=1}^M I_{yp} i_{yp} \quad [2]$$

Where i_{yp} (p=1, 2, 3.. M) is described by [9]:

$$i_{yp} = \begin{cases} 1 & y_{p-1} \leq y \leq y_p \\ 0 & elsewhere \end{cases} \quad [3]$$

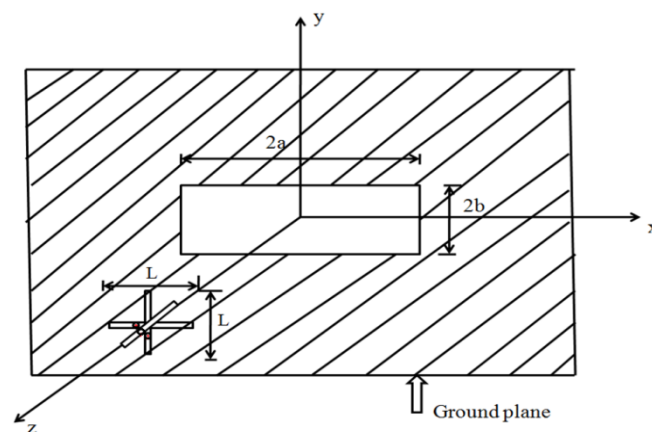


Figure 1 Measuring units in the near-field of the transmitter

Similarly current on the cross-pole (along x-axis) is designated by [9]:

$$I = \hat{u}_x \sum_{p=1}^M I_{xp} i_{xp} \quad [4]$$

$$\text{Where } i_{xp} = \begin{cases} 1 & x_{p-1} \leq x \leq x_p \\ 0 & elsewhere \end{cases} \quad [5]$$

Similarly current on the z-axis directed dipole of the near-field probe is designated by:

$$I = \hat{u}_z \sum_{p=1}^M I_{zp} i_{zp} \quad [6]$$

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$$\text{Where } i_{zp} = \begin{cases} 1 & z_{p-1} \leq z \leq z_p \\ 0 & \text{elsewhere} \end{cases} \quad [7]$$

Where I_{yp} , I_{xp} and I_{zp} are the coefficients of the pulse basis function for the co-pole, cross pole and z-directed dipole

The transmitted magnetic field is given by [8]:

$$H_x^{ext} = -\frac{ab}{\pi^2 k \eta} \sum_{p=1}^M E_p^1 \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} \frac{k^2 - k_x^2}{(k^2 - k_x^2 - k_y^2)^{\frac{1}{2}}} \text{sinc}(k_y b) \left\{ \begin{array}{l} j \sin(k_x a) \quad p \text{ even} \\ \cos(k_x a) \quad p \text{ odd} \end{array} \right\} \frac{\frac{p\pi}{2} \left\{ 1 - \left(\frac{2ak_x}{p\pi} \right)^2 \right\}}{e^{j(k_x x + k_y y)}} dk_x dk_y \quad [8]$$

The transmitted electric field is given by [8]:

$$E_y = -\frac{ab}{\pi^2} \sum_{p=1}^M E_p \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} \text{sinc}(k_y b) \left\{ \begin{array}{l} j \sin(k_x a) \quad p \text{ even} \\ \cos(k_x a) \quad p \text{ odd} \end{array} \right\} \frac{\frac{p\pi}{2} \left\{ 1 - \left(\frac{2ak_x}{p\pi} \right)^2 \right\}}{e^{j(k_x x + k_y y - k_z z)}} dk_x dk_y \quad [9]$$

$$E_z = -\frac{ab}{\pi^2} \sum_{p=1}^M E_p \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} \frac{k_y}{k_z} \text{sinc}(k_y b) \left\{ \begin{array}{l} j \sin(k_x a) \quad p \text{ even} \\ \cos(k_x a) \quad p \text{ odd} \end{array} \right\} \frac{\frac{p\pi}{2} \left\{ 1 - \left(\frac{2ak_x}{p\pi} \right)^2 \right\}}{e^{j(k_x x + k_y y - k_z z)}} dk_x dk_y \quad [10]$$

Internally scattered magnetic is given by [9]:

$$H_x^{int} = \sum_{p=1}^M E_p Y_{p0} \sin \left\{ \frac{m\pi}{2a} (x + a) \right\} \quad [11]$$

At inspection position, on the axis of co-pole, the y-component scattered field given by [9]:

$$E_y^s = \frac{\lambda \sqrt{\frac{\mu}{\epsilon}}}{8\pi^2 j} \int_{-l/2}^{l/2} I_{yp} \frac{e^{-jkR_1}}{R_1^5} [(1 + jkR_1)(2R_1^2 - 3a_w^2) + k^2 a_w^2 R_1^2] dy' \quad [12]$$

$$\text{Where } R_1 = \sqrt{a_w^2 + (y - y')^2}$$

At inspection position, on the axis of cross-pole, the x-component scattered field given by [9]:

$$E_x^s = \frac{\lambda \sqrt{\frac{\mu}{\epsilon}}}{8\pi^2 j} \int_{-l/2}^{l/2} I_{xp} \frac{e^{-jkR_2}}{R_2^5} [(1 + jkR_2)(2R_2^2 - 3a_w^2) + k^2 a_w^2 R_2^2] dx' \quad [13]$$

$$\text{Where } R_2 = \sqrt{a_w^2 + (x - x')^2}$$

Similarly the scattered field at the z-axis oriented dipole pole is given by:

$$E_z^s = \frac{\lambda \sqrt{\frac{\mu}{\epsilon}}}{8\pi^2 j} \int_{-l/2}^{l/2} I_{zp} \frac{e^{-jkR_3}}{R_3^5} [(1 + jkR_3)(2R_3^2 - 3a_w^2) + k^2 a_w^2 R_3^2] dz' \quad [14]$$

$$\text{Where } R_3 = \sqrt{a_w^2 + (z - z')^2}$$

The field due to mutual coupling between co-pole and cross-pole is realized as [9]:

$$E_y^{mx} = \frac{\lambda \sqrt{\frac{\mu}{\epsilon}}}{16\pi^3 j} \int_{x'=-l/2}^{l/2} \int_{\phi'=0}^{2\pi} I_{xp} \frac{e^{-jkR_4} (x-x')(y-y')(3+3jkR_4-k^2R_4^2)}{R_4^5} dx' d\phi' \quad [15]$$

$$\text{Where } R_4 = \sqrt{\rho^2 + a_w^2 - 2\rho a_w \cos\phi' (x - x')^2}$$

The field due to mutual coupling between cross-pole and co-pole is realized as [9]:

$$E_x^{my} = \frac{\lambda \sqrt{\frac{\mu}{\epsilon}}}{16\pi^3 j} \int_{y'=-l/2}^{l/2} \int_{\phi'=0}^{2\pi} I_{yp} \frac{e^{-jkR_5} (x-x')(y-y')(3+3jkR_5-k^2R_5^2)}{R_5^5} dy' d\phi' \quad [16]$$

The field on the z-directed dipole due to current on the cross-pole is given by:

$$E_z^{mx} = \frac{\lambda \sqrt{\frac{\mu}{\epsilon}}}{16\pi^3 j} \int_{x'=-l/2}^{l/2} \int_{\phi'=0}^{2\pi} I_{xp} \frac{e^{-jkR_3} (x-x')(z-z')(3+3jkR_3-k^2R_3^2)}{R_3^5} dx' d\phi' \quad [17]$$

$$\text{Where } R_3 = \sqrt{a_w^2 + (z - z')^2}$$

The field on the z-directed dipole due to current on the co-pole is given by:

$$E_z^{my} = \frac{\lambda \sqrt{\frac{\mu}{\epsilon}}}{16\pi^3 j} \int_{y'=-l/2}^{l/2} \int_{\phi'=0}^{2\pi} I_{yp} \frac{e^{-jkR_3} (y-y')(z-z')(3+3jkR_3-k^2R_3^2)}{R_3^5} dy' d\phi' \quad [19]$$

$$\text{Where } R_3 = \sqrt{a_w^2 + (z - z')^2}$$

III. IMPOSITION OF BOUNDARY CONDITION

The boundary conditions are forced at the opening, on the co-pole, on the cross-pole and on the z-directed measuring unit. The boundary conditions at the area of the opening and on the axis measuring probe are tangential component of the magnetic field, both within and outer surface of the waveguide is identical and the total tangential component of the electric field is zero respectively.

By the theory of superposition, the x-component of the magnetic field is given by

$$\text{At the } z=0 \text{ plane, using superposition, } 2H_x^{inc} + 2H_x^{int1} = H_x^{ext1} + H_x^{extco} + H_x^{extcr} + H_x^{extzd} \quad [20]$$

Parallel to the axis the three dipole fields are respectively given by

$$E_y^{inc} + E_y^{mx} + E_y^{scat} + E_y^{mz} = 0 \quad [21]$$

$$E_x^{inc} + E_x^{my} + E_x^{scat} + E_x^{mz} = 0 \quad [22]$$

$$E_z^{inc} + E_z^{mx} + E_z^{scat} + E_z^{my} = 0 \quad [23]$$

The weighting functions for aperture and dipole are defined as follows:



$$w_q^1 = \begin{cases} \sin\left\{\frac{q\pi}{2a}(x+a)\right\} & -a \leq x \leq a \\ 0 & \text{elsewhere} \end{cases} \quad [24]$$

$$\langle H, w_q^1 \rangle = \iint_{\text{surface}} H, w_q^1 dx dy \quad [25]$$

$$w_q^2 = [\delta(h - h_q)] = [\delta(h - h_1), \delta(h - h_2), \dots] \quad [26]$$

Where h and h_q Specifies a some reference point and a point at which the boundary conditions are enforced respectively.

$$\langle E, w_q^2 \rangle = \iint_{\text{surface}} E, w_q^2 ds \quad [27]$$

With the help of Equations [20], [21], [22]) and [23] and definition in Equations [25] and [27] and converting into matrix form, the co-efficients of global and pulse basis functions are at the same time determined. From this measuring unit (probe) voltage is determined.

IV. NUMERICAL RESULTS

The radiator opening is excited by a typical X-band WR-90 waveguide is used as a transmitter and three dipoles, each of length 0.47λ and radius 0.005λ , are used as a measuring unit. The load of 50Ω is attached at the co-pole, cross-pole and z-axis directed dipole at an off center of the dipoles as shown in Figure 1. For the calculation of coefficients of the basis functions, the program written in MATLAB 12. First, computation was carried out for the calibration of the measuring unit, when the plane wave, which is normal to the co-pole, is assumed to be an incident with field strengths of a 1volt / meter. Since the electric field is normal to the cross-pole, there should not be any voltage due to the incident wave. However, due to effects of mutual coupling between the poles, there will be an induced voltage and this is illustrated in Figure 2 and Figure 3. When the circularly polarized wave is incident on the probe, the magnitude of the induced voltage is almost the same in both the poles, whereas the phase is changed and the phase difference between co-pole and cross-pole induced voltages is less than 90 degrees as illustrated in Figure 4 and Figure 5.

The calculation has been done to test the co-pole voltage and field (with no measuring unit) at 10 GHz to evaluate the normalized (relative) tested co-pole voltage with the relative tested field (with no measuring unit). Since the relative tested co-pole voltage and field are verified, no error is enforced. These graphs are shown in Figure 6, Figure 7 and Figure 8 at a distance of $x=0$, and $z=0.15\lambda$, 0.25λ and 0.5λ respectively. The inaccuracy in the voltage with respect to the field (with no measuring unit) is determined. The tested co-pole voltage phase and tested field phase (without probe) at $x=0$, and $z=0.15\lambda$, 0.25λ and 0.5λ and are shown in Figure9, Figure 10 and Figure 11 respectively.

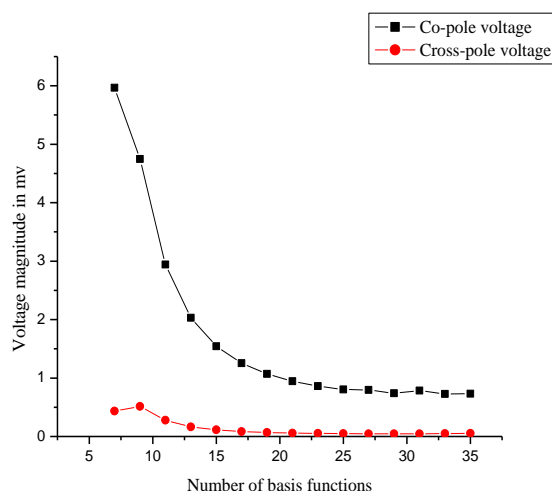


Figure 2 Co-pole and cross-pole voltages (magnitude) for the plane wave (far-field) incident on the crossed-dipole, when the wave normal to the co-pole has 1volt/meter field strength.

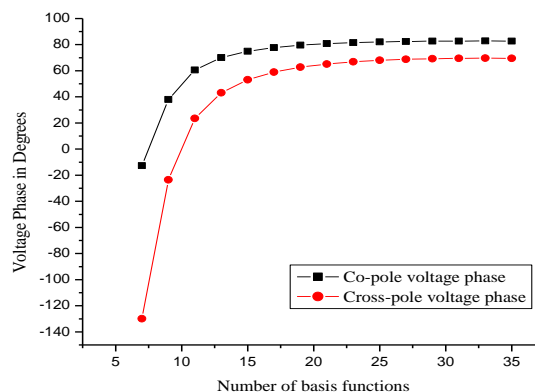


Figure 3 Co-pole and cross-pole voltage phases for the plane wave (far-field) incident on the crossed-dipole, when the wave normal to the co-pole has 1volt/meter field strength.

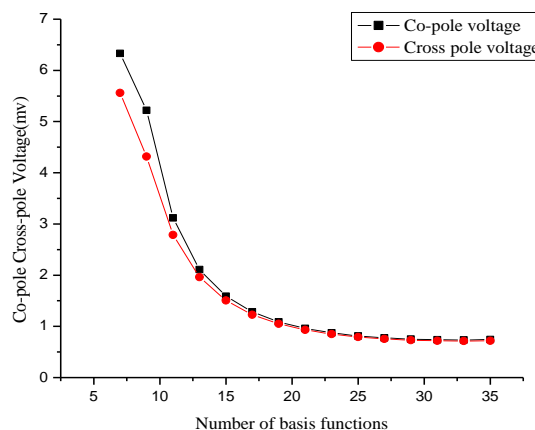


Figure 4 Co-pole and cross-pole voltages for the circularly polarized wave incident on the crossed-dipole.

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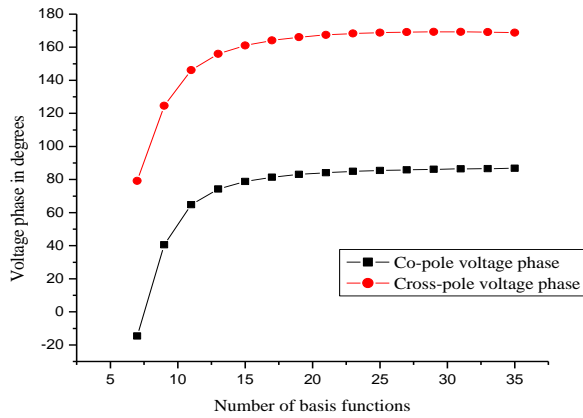


Figure 5 Co-pole and cross-pole voltage phases for the circularly polarized wave incident on the crossed-dipole.

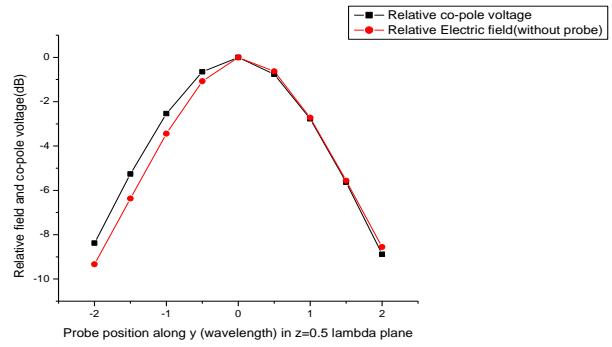


Figure 8 Normalized electric field (without probe) and normalized probe voltage in y-x plane at x = zero, z = 0.5 lambda, at a frequency of 10GHz.

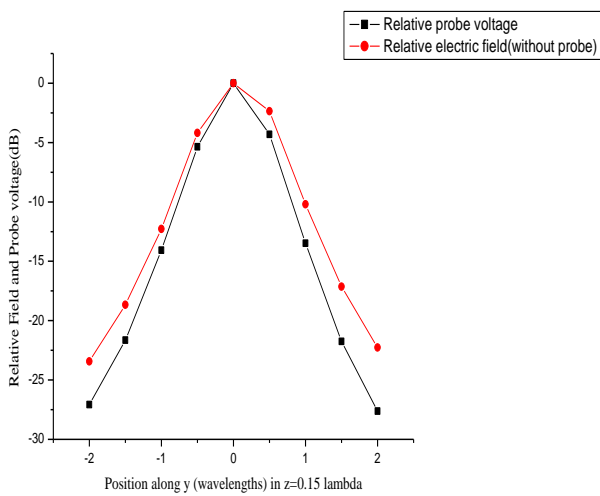


Figure 6 Normalized electric field (without probe) and normalized probe voltage in y-x plane at x = zero, z = 0.15 lambda, at a frequency of 10GHz.

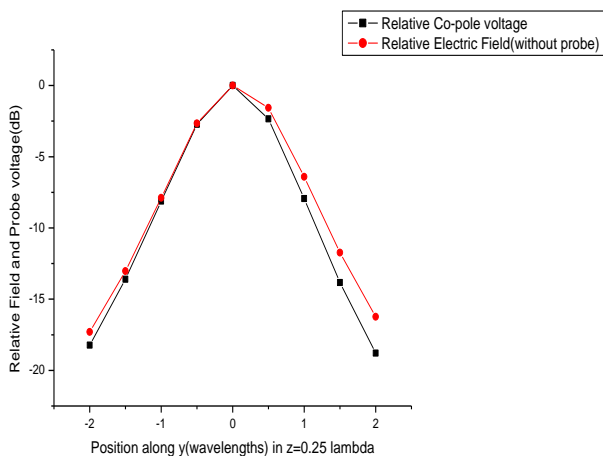


Figure 7 Normalized electric field (without probe) and normalized probe voltage in y-x plane at x = zero, z = 0.25 lambda, at a frequency of 10GHz.

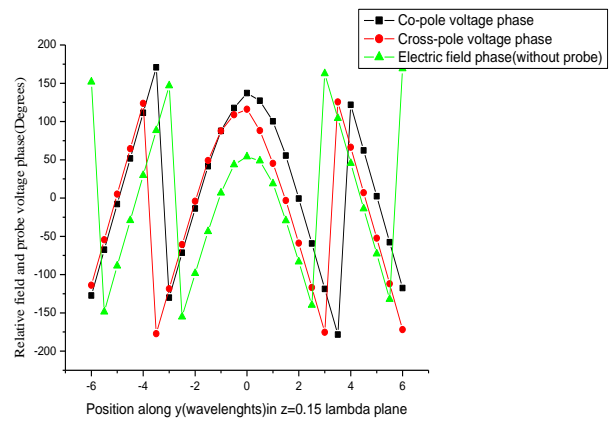


Figure 9 Normalized (relative) electric field pattern by eliminating the probe and normalized probe voltage phases in x-y plane at x=0, z = 0.15 lambda, at a frequency of 10GHz.

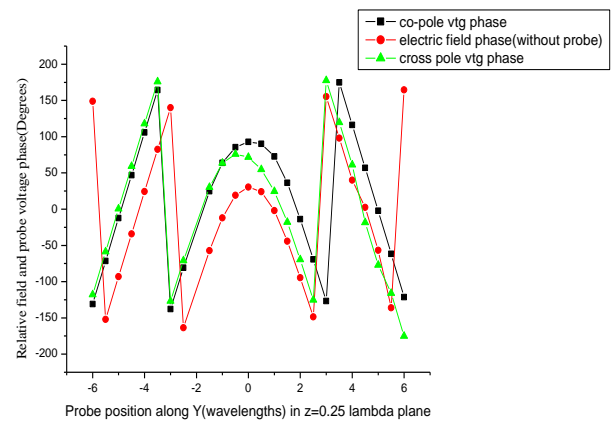


Figure 10 Normalized (relative) electric field pattern by eliminating the probe and normalized probe voltage phases in x-y plane at x=0, z = 0.25 lambda, at a frequency of 10GHz.

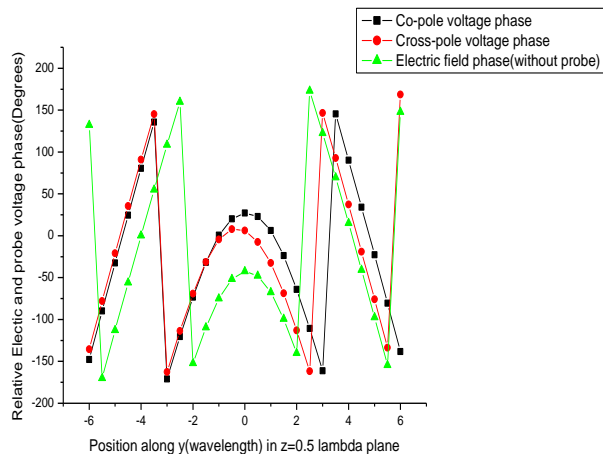


Figure 11 Normalized (relative) electric field pattern by eliminating the probe and normalized probe voltage phases in x-y plane at $x=0$, $z = 0.5 \lambda$, at a frequency of 10GHz.

CONCLUSION

The dipoles are considered as a measuring units, because of multiple reflections and effects of mutual coupling between poles of the measuring units produces inaccuracy. Since the cross-pole is parallel to the x-axis, the radiated electric field is zero in this direction and consequently we cannot compare the field and cross-pole and z-directed voltage, although there is a small cross-pole voltage induced because of the mutual coupling effects. From the computation, it can be observed that the phase difference between co-pole and cross-pole voltage phases deviated from 90 degrees, because of the mutual coupling effects. The error in the relative tested co-pole voltage with respect to the relative sampled field (with no measuring unit) pattern is presented in Figures 6, 7 and 8. As the probe approaches the transmitter, the error induced by the probe is increased. Figure 9, 10 and 11 shows the variation of the co-pole voltage phase with respect to electric field phase (co-pole direction) in the scan plane. However, due to multiple reflections between the transmitter and measuring unit, near-field values are altered.

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