Far-Field Gain Measurement Using a New Expression of Near-Field Gain Correction and Photonic Sensor

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Abstract

A new expression of near-field gain correction for antenna far-field on-axis gain measurement is proposed. Using the corrections, the antenna far-field on-axis gains are obtained from the measurements of the on-axis near-field transmissions between antennas and planar near-field scanning measurements using a photonic sensor. Measurements for double-ridged waveguide horns are shown to demonstrate the applicability of the correction.

Keywords : Far-field gain Near-field gain correction Photonic sensor Planar near-field scanning

1. Introduction

The accurate measurements of the antenna far-field on-axis gains are primary importance in antenna measurements. The conventional method for antenna far-field on-axis gains uses the transmission measurements between antennas whose distance are far enough to fulfil the far-field conditions [1], or the near-field gain corrections to the transmission measurements between antennas at finite distances less than the distances of the far-field conditions [2, 3].

The conventional near-field correction is calculated using the electric and magnetic fields at the apertures of antennas. Usually the electric and magnetic fields are calculated from the theoretical field distributions at the apertures of pyramidal horn antennas. For some complicated antennas such as double-ridged waveguide horn, it is difficult to calculate the field distributions and estimate the uncertainties of the calculated results.

From the theory of the planar near-field scanning method [4], the transmission between antennas at any distance can be expressed by the transverse vectorial transmitting characteristics (omitting " transversal vectorial" below) of the antennas. Using the transmitting characteristics, the far-field transmission can be obtained. Therefore the near-field correction at any distance is expressed by the ratio of far-field transmission to near-field transmission. This is a new expression of the near-field gain correction.

Using the photonic sensor and the planar near-field scanning method [5], the relative (not absolute) transmitting characteristics can be obtained by the Fourier Transform to the S_{21} measured by a vector network analyzer, without probe compensation.

The new expression of the near-field correction has the advantages:

1. There is no need to correct the measured S_{21} using error terms representing the measurement system;
2. There is no need to measure the reflection coefficients of the antennas;
3. The error terms representing the measurement system for each antenna can be different.

Measurements using the double-ridged waveguide horn antennas demonstrate the applicability of the proposed near-field gain correction.

2. New expression of near-field correction

The transmission S_{21} between a transmitting antenna (1) and a receiving antenna (2) is represented as [4]

$$S_{21}(\mathbf{R},d) = \int \mathbf{S}_{02}(\mathbf{K}) \bullet \mathbf{S}_{10}(\mathbf{K}) e^{-j\gamma d - j\mathbf{K}\bullet\mathbf{R}} d\mathbf{K} \tag{1}$$

where $\mathbf{S}_{02}$ is the transversal vectorial receiving characteristic of the antenna 2, $\mathbf{S}_{10}$ is the transmitting characteristic of the antenna 1, $\mathbf{R}$ is the transversal vector of the position vector of the antenna 2 relative to the antenna 1, z is the z component, $\mathbf{K}$ and γ is the transversal vector and the z component of the wavenumber vector $\boldsymbol{k}$ respectively. Throughout this paper, the multiple reflections between antennas are neglected.

From the Friis transmission formula [1] and using the near-field gains, the on-axis transmission power ratio is represented as

$$\left|S_{21}(\mathbf{0},d)\right|^2 = \left(\tfrac{\lambda}{4\pi d}\right)^2 (1-\left|S_{11}\right|^2)(1-\left|S_{22}\right|^2) G_1(d) G_2(d) \tag{2}$$

where $G_i(d)$, S_{ii} are the near-field gain and the reflection coefficient of the antenna i. Therefore the near-field correction (NFC) of the gain product is defined as

$$\begin{aligned} NFC &\equiv \frac{\lim_{d\to\infty}\left|dS_{21}(\mathbf{0},d)e^{jkd}\right|^2}{\left|dS_{21}(\mathbf{0},d)e^{jkd}\right|^2} \\ &= \frac{G_1(\infty)G_2(\infty)}{G_1(d)G_2(d)} \\ &= \frac{\lim_{d\to\infty}\left|d\int \mathbf{S}_{02}(\mathbf{K})\bullet\mathbf{S}_{10}(\mathbf{K})e^{jd(k-\gamma)}d\mathbf{K}\right|^2}{\left|d\int \mathbf{S}_{02}(\mathbf{K})\bullet\mathbf{S}_{10}(\mathbf{K})e^{jd(k-\gamma)}d\mathbf{K}\right|^2} \\ &= \frac{\left|2\pi k\mathbf{S}_{02}(\mathbf{0})\bullet\mathbf{S}_{10}(\mathbf{0})\right|^2}{\left|d\int \mathbf{S}_{02}(\mathbf{K})\bullet\mathbf{S}_{10}(\mathbf{K})e^{jd(k-\gamma)}d\mathbf{K}\right|^2} \end{aligned} \tag{3}$$

Equation (3) can be expressed in the electromagnetic fields at the aperture of the antenna 2 [4] and is equivalent to the conventional expression in [2, 3] if the two antennas are reciprocal.

If the antenna 2 is reciprocal (the antenna 1 is not necessary to be reciprocal), the NFC is represented as

$$NFC = \frac{\left|2\pi k\mathbf{S}_{20}(\mathbf{0})\bullet\mathbf{S}_{10}(\mathbf{0})\right|^2}{\left|d\int \frac{1}{\gamma}\left[\gamma^2\mathbf{S}_{20}(\mathbf{K})\bullet\mathbf{S}_{10}(\mathbf{K}) + \{\mathbf{K}\bullet\mathbf{S}_{20}(\mathbf{K})\}\{\mathbf{K}\bullet\mathbf{S}_{10}(\mathbf{K})\}\right]e^{jd(k-\gamma)}d\mathbf{K}\right|^2} \tag{4}$$

where $\mathbf{S}_{20}$ is the transmitting characteristic of the antenna 2. This is the new expression of the NFC.

If the photonic sensor is used, it is easy to measure the transmitting characteristics $\mathbf{S}_{20}$ and $\mathbf{S}_{10}$ because the transmitting characteristics are obtained from the Fourier transform of the S_{21} measured by a two port vector network analyzer (VNA). The measured $S_{21i}(\mathbf{R}, d_i)$ is proportional to the electric field $\mathbf{E}_i(\mathbf{R}, d_i)$ transmitted by the antenna i as

$$S_{21i}(\mathbf{R},d_i) = \alpha_i \hat{\mathbf{p}} \bullet \mathbf{E}_i(\mathbf{R},d_i) \tag{5}$$

where α_i is a constant including the error terms of the system and the refection coefficient of the antenna i, $\hat{\mathbf{p}}$ is the unit vector parallel to the dipole moment vector of the photonic sensor [5]. The electric field $\mathbf{E}_i(\mathbf{R}, d_i)$ and the transmission characteristic $\mathbf{S}_{i0}$ are related as [4]

$$\mathbf{S}_{i0}(\mathbf{K}) = \frac{e^{j\gamma d_i}}{2\pi a_0}\int \mathbf{E}_{it}(\mathbf{R},d_i)e^{+j\mathbf{K}\bullet\mathbf{R}}d\mathbf{K} \tag{6}$$

where $\mathbf{E}_{it}(\mathbf{R}, d_i)$ is the transversal vector of the $\mathbf{E}_i(\mathbf{R}, d_i)$ and a_0 is the incoming wave amplitude of the antenna i. Therefore directing the dipole moment of the photonic sensor to the x axis and the y axis, we can measure the corresponding components of the electric field and determine the transmitting characteristic of the antenna i.

It should be noted that α_i can be different for each antenna measurement because the constants appearing in the numerator and the denominator of the equation (4) are cancelled each other. This means that the error terms of the system and the reflection coefficient of each antenna is not related to the NFC. This is the most important merit in the measurement using amplifiers between the antenna and the VNA.

3. Measurement and NFC for Double-Ridged Waveguide Horn

The near-field gains at 3 m were determined by the three antenna method [1]. The measured frequencies are from 1 GHz to 6 GHz with 0.5 GHz steps. The measured antennas were one EMCO 3115 (designated as Old type) and two ETS-Lindgren 3115 (designated as New type).

To determine the transmitting characteristics, the measurement system using the photonic sensor is used as in Fig. 1. The photonic sensor is the same as Ref. [5]. The gain of the amplifier (HP8348A) is about 35 dB. The output power and the IF of the VNA (Agilent E8363C) are 0 dBm and 100 Hz respectively. The scanned range is 1.9 m x 1.9 m in the planar scanner (NSI 300V-8x8). The distance between the aperture of each antenna and the photonic sensor is 58 mm.

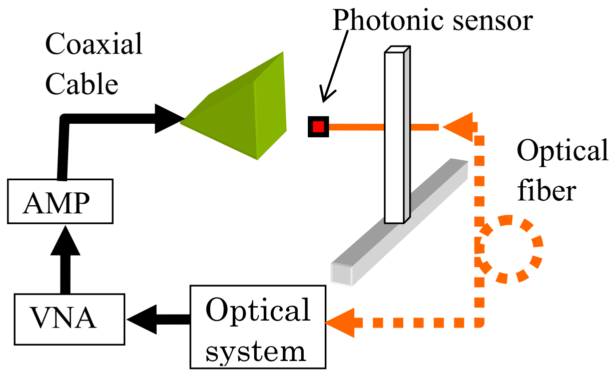
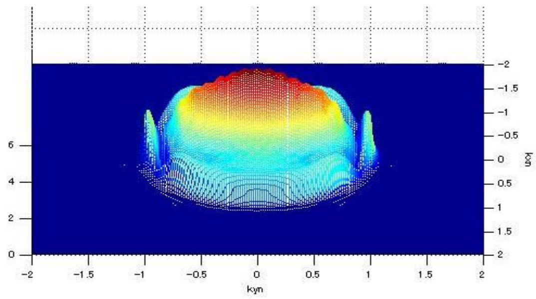
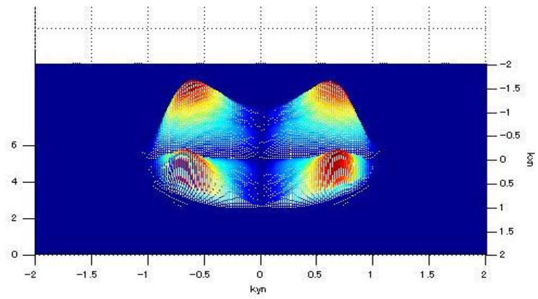


Figure 1: Measurement system using the photonic sensor and the planar near-field scanner.

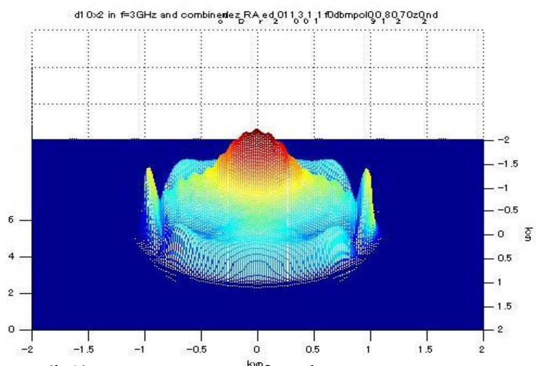
Examples of the measured transmitting characteristics of the old-type antenna and the new-type antenna are shown in Fig. 2. The x-y axis is the normalized **K** divided by *k*. The z axis is the amplitude of each component in linear scale. The E planes of the antennas are in the x axis.



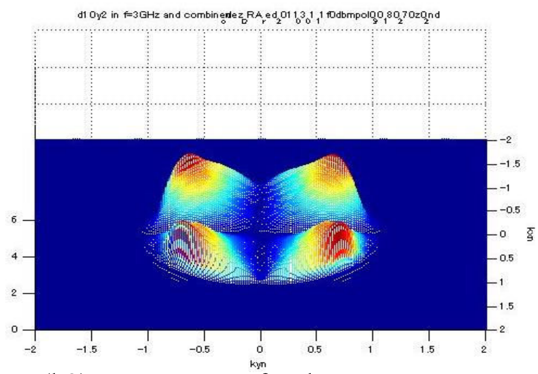
(a1) x component for the old type



(a2) y component for the old type

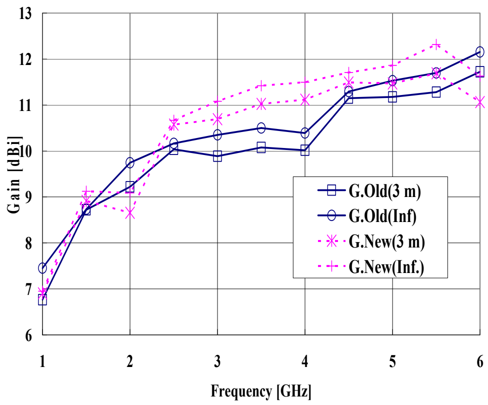


(b1) x component for the new type

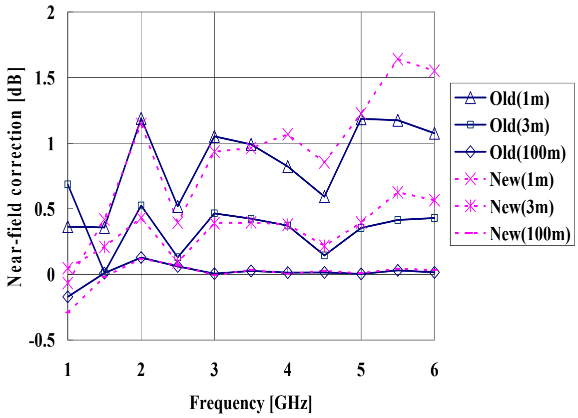


(b2) y component for the new type

Figure 2: Transmitting characteristics of the old-type and new-type antennas at 3 GHz.



(a) Gains of the old-type and new-type antennas at 3 m and infinity.



(b) NFCs of the old-type and new-type antennas at 1m, 3 m and 100.

Figure 3: Gains and NFCs of the old-type and new-type antennas at various distances.

Using the transmitting characteristics of the old-type and new-type antennas in Fig. 2, the NFC at any distance can be calculated from the equation (4). Therefore the near-field gains at 3m measured by the conventional three-antenna method are converted to the gains at infinity. The results are shown in Fig. 3 (a).

The NFCs at 1 m, 3 m, and 100 m are shown in Fig. 3 (b) because the gains at 1 m often used in EMC society and the NFCs at 100 m (considered to be equivalent to infinity) are used as validity check of the numerical integration of the denominator of the equation (4). From Fig. 3 (b), the NFCs below 3 GHz seem to be not accurate due to the truncation errors in the transmission characteristics.

5. Summary

The new expression of the near-field gain correction for the on-axis near-field antenna gain measurement has been proposed. The proposed expression uses the antenna transmitting characteristics that are measured by the planar near-field scanning method. By using the photonic sensor, the transmitting characteristics are determined without the probe compensation and there are various advantages in the measurements because of no need to know the photonic probe characteristics, the reflection coefficients of the measured antenna, and the error terms of the system.

We are now studying to estimate the uncertainty of the proposed NFC and to reduce the truncation error below 3 GHz in order to extend the application frequency range below 3 GHz.

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