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THE PREDICTION OF RADIATING PATTERN BY USING NEAR-FIELD MEASUREMENTS

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1. Introduction

Antennas serve as transducers between electromagnetic waves traveling in free space and guided electromagnetic signals in circuits. One of basic antenna parameters is radiating pattern from antenna[1]. Measurement of radiating patterns requires large open area or anechoic chamber, in which the testing system involves setting the antenna at specified distances from the system under test (SUT). FCC and CISPR regulations use distances of 3 and 10 meters [2]. Measurement under their regulations needs large space. The computation of far-field from near-field measurements bypasses the problems and requirements of direct far-field measurements such as open range, good characterization of the site attenuation, and logistic problems[3]. The author proposed a new near-to-far-field transformation for the finite difference time domain (FDTD) method [4]. In the conventional FDTD method, electromagnetic field nearby objects can be analyzed, however, the surface numerical integration is required for getting the far-field data, e.g. scattering patterns or radiating patterns [5]. Applying the proposed method, the far-field data can be obtained accurately by using the cylindrical function.

In this paper, the above proposed method is applied to measurement of radiating patterns from antennas or radiating objects of EMI. Using this extended method, the far-field data can be obtained without large free space. In order to verify this extension, the prediction of radiating pattern by using near-field experiment is performed for Yagi antenna. Moreover, two types measurement system is suggested, which employ the vector network analyzer.

2. Cylindrical functions

Let us consider a two-dimensional problem. Most of electromagnetic radiation problems from radiating objects, such as antennas or electrical equipment, are discussed in two-dimensional cross-sections. Electromagnetic wave from two-dimensional radiating objects can be represented in the cylindrical functions, which are in the form of exact series solutions with unknown expansion coefficients. As one of examples, let us consider that the radiated wave from single line source is polarized with the electric field parallel to the z-coordinate. The electric field E_z can be described in the Hankel function as follows :

$$E_z(\vec{r} \mid \vec{r}') = \frac{1}{4j} H_0^{(2)}\left(k_0 |\vec{r} - \vec{r}'|\right) \tag{1}$$

where $\vec{r}$ and $\vec{r}'$ are an observation point and a source point in the two-dimensional space, respectively. The $H_0^{(2)}$ is the *0-th* order Hankel function of the second kind, which is the two-dimensional Green's function. The k_0 is the wave number in free space.

Radiated electric field E_z from the radiating objects can be described in terms of a generalized series of the Hankel function as follows :

$$E_z(r,\theta) = \sum_{n=-\infty}^{\infty} c_n H_n^{(2)}(k_0 r) \cdot \exp(jn\theta) \tag{2}$$

where c_n is the unknown coefficient, $H_n^{(2)}$ is the *n-th* order Hankel function of the second kind.

The chief aim of this method is to obtain radiating patterns by measuring the near-field

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electromagnetic wave without large space. In order to obtain radiating patterns, the unknown coefficients c_n in (2) have to be given. The unknown coefficients c_n can be determined from boundary condition, therefore in this method space for the problem is partitioned into two subregions by introducing a virtual boundary.

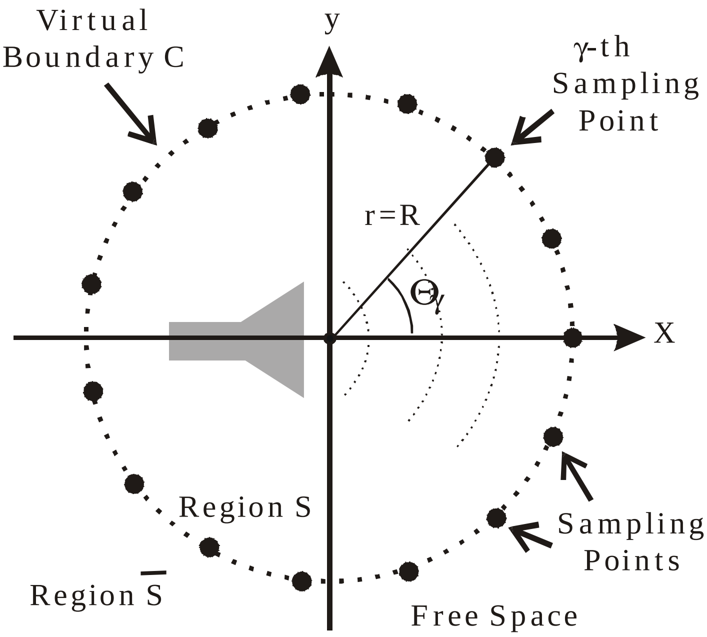

Fig. 1 Cross section of geometrical configuration.

The virtual boundary is applied to the free space, which surrounds the radiating objects, it is named *Virtual boundary* C . The inside region of the virtual boundary C is named $\mathrm{Re}\,gion\ S$ (interior-region), the outside region is called $\mathrm{Re}\,gion\ \bar{S}$ (exterior-region). In the $\mathrm{Re}\,gion\ \bar{S}$, radiated electric field is represented in the cylindrical functions, that is (2) with the unknown coefficients c_n. On the other hand, the radiated electric field in the vicinity of radiating objects is measured in $\mathrm{Re}\,gion\ S$. The boundary condition is continuity between the tangential electric field components of the cylindrical functions and the measured data on the virtual boundary C .

That is

$$E_z^{\mathrm{Re}\,gion\ S}\Big|_C = E_z^{\mathrm{Re}\,gion\ \bar{S}}\Big|_C \tag{3}$$

where the left side of (3) denotes the electric field from the results of measurements in $\mathrm{Re}\,gion\ S$, and the right side of (3) means the electric field represented by cylindrical functions in $\mathrm{Re}\,gion\ \bar{S}$.

The boundary condition is satisfied on all sampling points that are placed on the virtual boundary C at even intervals. The central angle between the $\gamma - th$ sampling point and the x-axis is defined by

$$\theta_\gamma = \frac{2\pi\gamma}{2N+1} \qquad \left(\gamma = 0, \pm 1, \pm 2, \cdots, \pm N\right) \tag{4}$$

where (2N+1) is the total number of sampling points.

Cross section of geometrical configuration is shown in Fig.1, solid circles on the virtual boundary C denote the sampling points.

In the first instance, near electric field around the radiating objects is measured in $\mathrm{Re}\,gion\ S$. The results of measurements are in complex phasor, which is obtained by using a vector network analyzers in terms of magnitude and phase. Then, applying the (3) to all the sampling points on *Virtual boundary C,* a complex (2N+1) X (2N+1) square matrix equation is formulated as :

$$\begin{bmatrix} E_z^{\mathrm{Region}\,S}(k_0R,\theta_{-N}) \\ \vdots \\ E_z^{\mathrm{Region}\,S}(k_0R,\theta_N) \end{bmatrix} = \begin{bmatrix} H_{-N}^{(2)}(k_0R)e^{j(-N)\theta_{-N}} & \cdots & H_N^{(2)}(k_0R)e^{jN\theta_{-N}} \\ \vdots & \ddots & \vdots \\ H_{-N}^{(2)}(k_0R)e^{j(-N)\theta_N} & \cdots & H_N^{(2)}(k_0R)e^{jN\theta_N} \end{bmatrix} \begin{bmatrix} c_{-N} \\ \vdots \\ c_N \end{bmatrix} \quad (5)$$

where R is the radius of *Virtual boundary C*, k_0 is the wave number in free space.
In above equation, $E_z^{\mathrm{Region}\,S}(k_0R,\theta_\gamma)$ $(\gamma = -N,\cdots,N)$ represents the complex electric field at a single operating frequency, which is the result of experiment in complex phasor. Solving the above square matrix equation, the unknown coefficients c_n $(n = -N,\cdots,N)$ are determined. Accordingly, the radiated electric fields can be obtained by (2) in the $\mathrm{Re}\,gion\,\bar{S}$.

In the far-field, the observation point is at infinity. Therefore, the argument of Hankel function $k_0 r$ tends towards infinity $(k_0 r >> 1)$ in (2) for the far-field data such as radiating patterns from antennas. Using asymptotic expansion of the Hankel function $H_n^{(2)}(k_0 r)$, the far-field data, that is the radiating pattern $F(\theta)$, is obtained, that is,

$$E_z^{\mathrm{Region}\,\bar{S}}(k_0 r >> 1) \approx \sqrt{\frac{2}{\pi k_0 r}} \exp\left(-jk_0 r + j\frac{\pi}{4} \right) \cdot F(\theta) \quad (6)$$

where

$$F(\theta) = \sum_{n=-N}^{N} c_n \exp\left\{ jn\left(\theta + \frac{\pi}{2} \right) \right\} \quad (7)$$

Once expansion coefficients c_n are given, it is possible to obtain the far-field data by (7).

3. Measurement system

In the presented method, the near-field data in the vicinity of radiating objects is employed for the far-field data, such as radiating pattern or scattering pattern. Near electric field is measured in phasor, therefore measurement system has to be equipped with ability to measure amplitude and phase of near electric field. Using vector network analyzer, the complex electric field can be measured.

A measurement system is proposed for one of examples. Vector network analyzer has two ports for measurement, Port-1 and Port-2. Each port has ability to measure the ratio of the vector quantities, which are incident, reflected and transmitted waves. Port-1 is connected to transmitting antenna as a SUT. The complex electric fields on all sampling points which encircle the SUT, are measured by using receiving probes. Each probe is placed at all sampling points. All receiving probes connect to Port-2 on vector network analyzer via a selector. Each wavelength from all probes to Port-2 via the selector must be identical. S-parameter S_{21}, that is transfer function from Port-1 to Port-2, is measured for each sampling point. In this method, phase difference between electric field at each sampling point is important. S-parameter S_{21}^{γ} represents the ratio of phasor between the SUT and the probe at the $\gamma - th$ sampling point, as follows:

$$S_{21}^{\gamma} = \frac{A_\gamma \cdot \exp(j\theta_\gamma)}{A_{SUT} \cdot \exp(j\theta_{SUT})} = \frac{A_\gamma}{A_{SUT}} \cdot \exp\{ j(\theta_\gamma - \theta_{SUT}) \} \quad (10)$$

where A_{SUT} and θ_{SUT} are the amplitude and phase on SUT (transmitting antenna), respectively. The A_γ and θ_γ are the amplitude and phase on probe at the $\gamma - th$ sampling point.
The phase θ_{SUT} on SUT varies with each measurement of S-parameter S_{21}^{γ} $(\gamma = -N,\cdots,N)$, however, the phase difference between the SUT and the probe at the $\gamma - th$ sampling point, $\theta_\gamma - \theta_{SUT}$, is invariable. Therefore, the transmitting wave on SUT has the role of reference wave. Moreover, relative phase difference between each sampling point are retained.

The above system requires many probes and selector, thus an alternative measurement system is also proposed, it is shown as Fig.2. In this system, only one probe is fixed and SUT is rotated alternatively. Then, S-parameter S_{21}^{γ} $(\gamma = -N,\cdots,N)$ are measured 2N+1 times with rotation of the SUT. Many probes and selector is not required in this measurement system. However, a mechanism of rotation for the SUT is necessary and 2N+1 times measurement is required.

4. Experimental Results

In order to check the proposed method, experimental verification was provided by the systems Fig.2. The operating frequency was 2.45GHz ($\lambda = 12.24cm$) and the radius of the virtual boundary *C* is $97.9cm$ ($R/\lambda = 8.0$). The 8-elements Yagi antenna was used as a SUT. A half-wavelength dipole was adopted as the receiving probe on the sampling points.

For comparison the conventional method is applied to the measurement of radiating patterns. One of experimental results is shown in Fig.3. Both results, this method and the conventional method give good agreement.

5. Conclusions

In this paper, new method for prediction of radiating patterns is proposed. In this method, the cylindrical function, i.e. Hankel function, is adopted for the near-to-far field transformation. Applying this method, far-field data, that is radiating patterns, can be easily obtained without large space. In order to verify the proposed method, microwave experiments were performed. A measurement system applied this method was proposed. In the system vector network analyzer is employed for the measurement of phasor. Experimental verification was provided. The result by proposed method give good agreement with the result from the conventional method.
Radiating patterns can be measured with compact systems by using the proposed method.

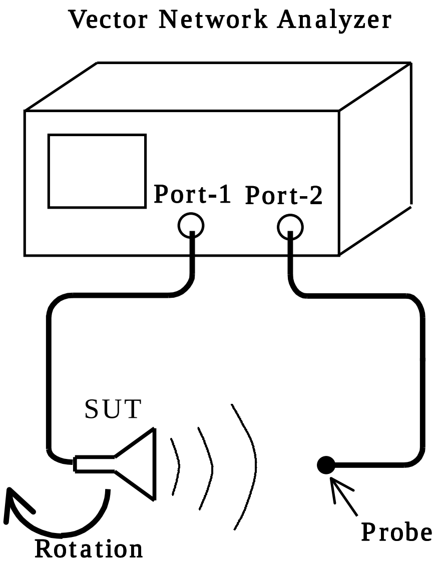

Fig. 2 Measurement system

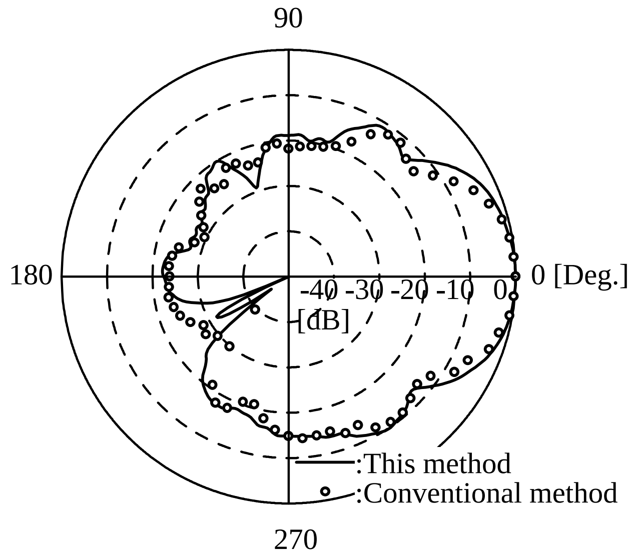

Fig.3 Experimental results

References

[1] M. Golio, et. al., “The RF and Microwave Handbook,” CRC Press, 2001.
[2] Information technology equipment, Radio disturbance characteristics-Limits and methods of measurement, CISPR 22, 1997.
[3] A. D. Yaghjian, “An overview of Near-Field Antenna Measurements,” IEEE Trans. Antennas Propagat., vol.34, no.1, pp.30-45, Jan. 1986.
[4] K. Motojima, and S. Kozaki, “A Hybrid Technique Combining FDTD and Series Solution for Near-to-Far-Field Transformation,” Int. J. of Infrared and Millimeter Waves, vol.23, No.1, pp.157-166, 2002.
[5] A. Taflove, “Computational Electrodynamics The Finite-Difference Time-Domain Method,” Artech House Publishers, pp. 203-226, 1995.