Antenna Radiation Field Pattern Interpolation Technique from Sparse Measurements According to Discrete Fourier Transform

Jake W. Liu (1), Hsi-Tseng Chou (1)
(1) Graduate Institute of Communication Engineering, National Taiwan University, Taiwan

Abstract

In this paper, an efficient method of field pattern interpolation is presented to calibrate the antenna radiation measured by sparse intervals. The technique takes the measurement in far field which lessens the interference caused by the measure antenna (MA). The sparse measurement is determined by the characteristics of discrete Fourier transform (DFT) between an aperture and its far-field radiation, by which the positions to measure the antenna radiation can be given for minimum efforts, and the measurement can be accelerated to acquire the field pattern. The procedure is outlined and some numerical examples are given to validate the method.

1 Introduction

Antenna radiation measurement is an important task in the area of electromagnetic engineering, since the final verification of antenna designing is unavoidable. The theory of antenna measurement has been studied for a long history. To acquire a three-dimensional (3-D) radiation pattern of an antenna, one can measure the near fields of the antenna under test (AUT) for its canonical surrounding surfaces (planar, cylindrical or spherical), and then find their far field radiation by the technique of near-field to far-field transformation [1]. However, the accuracy of the transformation depends on the number of the selected basis functions, and another serious problem is the presence of the measure antenna (MA) which causes interference effecting the radiation performance of the AUT.

Another method is to measure the far-field pattern directly under the far-field measurement systems such as the compact antenna test range (CATR) [2]. However, measurements acquiring a full 3-D radiation pattern are often time-cumbersome, and thus have shortcomings when efficient design procedure is required.

In previous studies, the work in [3] performs the interpolation based on two known patterns on the principle cuts. The fields are found by computing the weighting average from the known points. However, the method is confined to specific types of patterns as those of the base station antennas with good radiation behavior. Linear interpolation of the radiation field is also discussed in [4] with intensive mathematical details. A revision of the method proposed in [3] is given in [5].

In this paper, a far-field pattern interpolation method is proposed to recover the 3-D pattern from sparse measurement over field points which is determined by the relationship of discrete Fourier transform (DFT) between a radiating aperture and its far-field pattern. The radiation pattern should be deterministic theoretically when the samples of the field are chosen to fulfill the Nyquist limit [6]. However, such sampling requires high accuracy of the measurement in both theta and phi directions, and most antenna measurement systems are not capable of conducting measurement in this precision; Thus, an iterative procedure is also proposed to fix this problem, which is addressed in the following sections. This technique is particularly important and useful to accelerate the antenna calibration for an electrically large array of antennas.

2 Formulation

In this section, the method for determining the sampling points is firstly derived, and then the iterative algorithm is outlined to provide a complete procedure in order to recover the 3-D pattern.

2.1 Determination of the Field Sampling

From the theorem of planar near-field to far-field transformation [7], one is capable of determine the far-field radiation pattern with the near-field measurement by computing the spectral field

$$\overline{f}(k_x,k_y)=\int_{y_a}^{y_b}\int_{x_a}^{x_b}\overline{E}_{NF}(x',y')e^{j(k_x x'+k_y y')}dx'dy' \qquad (1)$$

where XX is the electric near-field distribution, and the integration is computed on the measured planar surface, with XX and XX the x and y component of the wavenumber. The far field at XX is then determined by

$$\overline{E}_{FF}(\overline{r})=C\cos\theta\,\overline{f}(k_x,k_y) \qquad (2)$$

where the constant $C=\dfrac{jke^{-jkr}}{2\pi r}$.

The 3-D pattern recovery is conducted in a similar fashion, but with sampling in the far field. The far-field sampling is first determined by an imaginary planar near-field sampling. Following the theory of planar near-field to far-field transformation in a DFT relationship, a near-field plane is selected to be larger than the AUT aperture size, with the sampling spacing in *x* and *y* direction (d_x

and d_y) lesser than half wavelength for good pattern recovery. Assume that the imaginary near-field sampling is

$$\begin{cases} x = (m - M/2)d_x \\ y = (n - N/2)d_y \end{cases}, \quad (3)$$

where M and N are the numbers of sampling in x and y direction, respectively (assumed even numbers as an example), and $m = \pm 0,1,2,...,M/2$, $n = \pm 0,1,2,...,N/2$.

Based on the radiation integral, the corresponding sampling in the spectral domain is determined by

$$\begin{cases} k_x = k \sin\theta \ \cos\phi \ = \dfrac{2\pi(m - M/2)}{Md_x} \\ k_y = k \sin\theta \ \sin\phi \ = \dfrac{2\pi(n - N/2)}{Nd_y} \end{cases}, \quad (4)$$

where k is the wave number. The formula above indicates that when a near-field scanning is performed according to (3), the transformed far field are located on the grids formed by k_x and k_y . Hence, the scan angles in far field can be derived from (4)

$$\begin{cases} \theta = \arcsin(\sqrt{(k_x/k)^2 + k_y/k)^2}) \\ \phi = \arctan(k_x/k_y) \end{cases}, \quad (5)$$

If the far-field values are measured according to 4), one is able to determine uniquely the 3-D pattern through sinc interpolation. It is noted that the points outside the unit circle of the normalized spectral domain will result in complex angles, and these values are simply omitted in the measurement. However, the computed angles according to (5) are often non-integers and the measurement systems are unable to acquire these field values with infinite precision. Thus, an iterative procedure is developed to relax this limitation.

2.2 Iterative Procedure for Approximated Angles in the Measurement

In the realistic procedure, the measurements are taken with the angles determined by (5) being rounded to integers. The iterative procedure first finds the field values on the (k_x, k_y) grid through scattered interpolation of the measured values [8], and the field values are back interpolated into (θ, ϕ) domain while remaining the measured fields unchanged. The process is repeated iteratively, with a cost function in the i^{th} iteration defined as

$$\text{cost}_i = \frac{\left\| f_{k_x,i} - f_{k_x,,i-1} \right\|_2}{\left\| f_{k_x,i-1} \right\|_2} + \frac{\left\| f_{k_y,i} - f_{k_y,i-1} \right\|_2}{\left\| f_{k_y,i-1} \right\|_2} \quad (6)$$

where f represents the spectral field values with its subscripts indicating the components and the number of iteration. $\|\cdot\|_2$ is the 2 norm of a vector. A threshold verifying the convergence of the process can be defined to stop the iteration.

A flow chart of the process is depicted in Fig. 1. It is noted that the selection of the imaginary near-field plan should be larger than the aperture size of the AUT (empirically, twice is preferable to acquire accurate results). Once the imaginary near-field sampling is determined, the field points to be measured are sought to serve as the data under calibration. Some results of the proposed interpolation technique will be shown in the next section as an illustration of the operation.

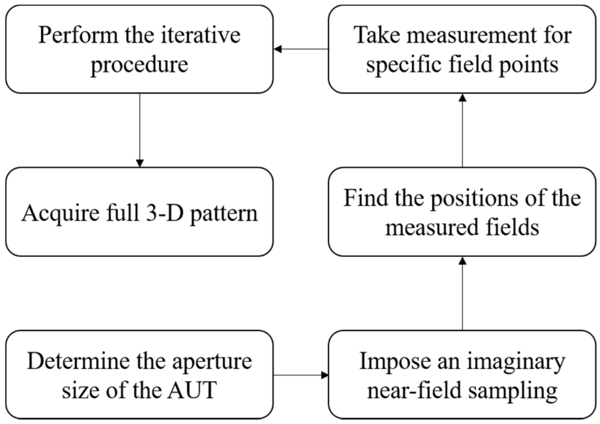

Figure 1. Flow chart of the proposed pattern interpolation technique.

3 Simulation Results

The technique presented in this paper is testified by a simulation example. In our simulation, we import a field pattern of an antenna which is simulated by the commercial software HFSS ant the calibration process is written in MATLAB. The field values that are not sampled are masked out as unknowns, and the result after calibration is compared to the full simulated pattern.

A 2.4 GHz 8 by 8 patch antenna array is used to testify the method. These patch antennas are assumingly realized on regular FR4 dielectric substrate to resonate at this frequency. The array periods are set as half wavelength. The excitations are uniform with equal phases for boresight radiation. It is capable of radiating electromagnetic fields with a directivity of 20.21 dB and a -3 dB beamwidth of 12 degrees. The pattern is simulated by the commercial software HFSS, and the simulated field pattern is masked to assemble the sparse measurement. The model of the patch array antenna is shown in Fig. 2. To determine the positions of the measured points, a 31 by 31 imaginary near-field planar sampling with spacing lower than half wavelength is imposed. Elliminating the complex angles, a total number of 749 measurements is needed to acquire the positive half-plane 3-D pattern, as compared to the traditional 3-D measurement with 181×361=65341 points of measrements if 1 degree precision is required in both directions.

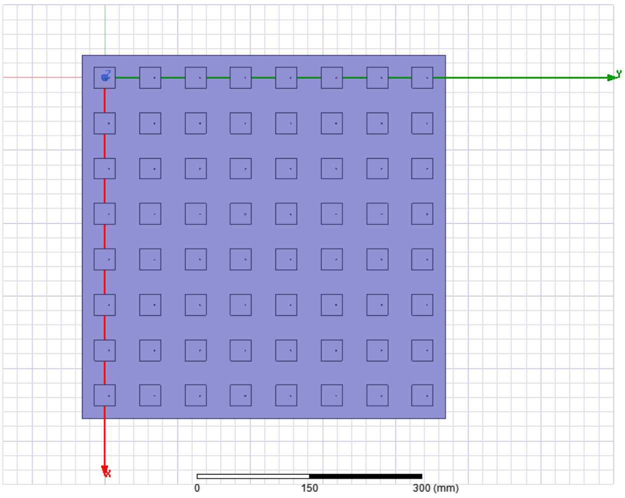

Figure 2. A 2.4 GHz 8 by 8 patch array.

The H-cut calibrated result is shown in Fig. 3, where the black curve represents the normalized simulated pattern, serving as a reference for comparison. On the other hand, the blue dots play as the role of the measured fields at the sparse points while the red curve shows the calibrated pattern using these sparse field points. The overlapping of radiation patterns is very well up to 80 degrees. The mismatch at the very far angles is caused by the ignorance of complex field points resulted from the (k_x, k_y) domain. In addition, the curve of computational convergence of the cost function in (4) is shown in Fig. 4. The convergence rate is very fast to achieve good results in just a few iterations. This computational times are much smaller than that using mechanical scans of measurement probes to measure the field points.

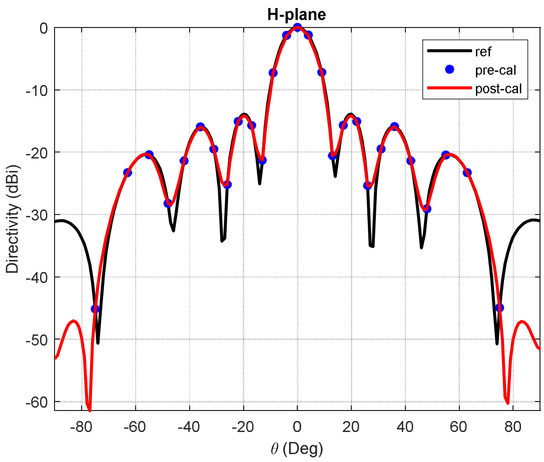

Figure 3. Results before and after calibration of example 1, as compared with the simulated pattern.

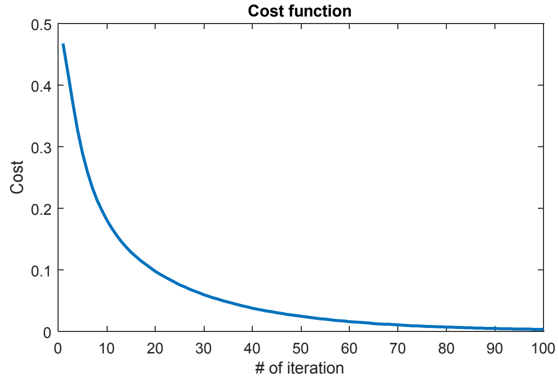

Figure 4. Curve of convergence.

4 Conclusion

In this paper, a method of interpolating the far-field radiation pattern with sparse measurement is derived. The measured field is firstly determined by the law of DFT, which requires the fields to be measured on the grids in accord with the Nyquist limit. Then, an iterative procedure is developed to fit the realistic situation that the accuracy of the measurement is limited. The procedure can be incorporated with a far-field measurement system such as CATR and can save time when a full 3-D radiation pattern is needed. The method is testified, and promising results are given. Further measurement experiments will appear in the future work.

5 Acknowledgements

Financial support from the Ministry of Science and Technology, Taiwan is acknowledged.

6 References

1. A. Yaghjian, "An overview of near-field antenna measurements," *IEEE Transactions on Antennas and Propagation*, **34**, 1, January 1986, pp. 30-45, doi: 10.1109/TAP.1986.1143727

2. Gregson, Stuart, et al. *Theory and practice of modern antenna range measurements*. The Institution of Engineering and Technology, 2014.

3. F. Gil, A. R. Claro, J. M. Ferreira, C. Pardelinha and L. M. Correia, "A 3D interpolation method for base-station-antenna radiation patterns," *IEEE Antennas and Propagation Magazine*, **43**, 2, April 2001, pp. 132-137, doi: 10.1109/74.924614

4. M. Robinson, "Knowledge-Based Antenna Pattern Interpolation," *IEEE Transactions on Antennas and Propagation*, **62**, 1, Jan. 2014, pp. 72-79, doi: 10.1109/TAP.2013.2287516

5. N. R. Leonor, R. F. S. Caldeirinha, M. G. Sánchez and T. R. Fernandes, "A Three-Dimensional Directive Antenna Pattern Interpolation Method," *IEEE Antennas and Wireless Propagation Letters*, **15**, pp. 881-884, 2016, doi: 10.1109/LAWP.2015.2478962

6. J. J. H. Wang, "An examination of the theory and practices of planar near-field measurement," *IEEE Transactions on Antennas and Propagation*, **36**, 6, June 1988, pp. 746-753, doi: 10.1109/8.1176

7. Gregson, Stuart, John McCormick, and Clive Parini. *Principles of planar near-field antenna measurements*, **53**, IET, 2007.

8. Amidror, Isaac. "Scattered data interpolation methods for electronic imaging systems: a survey," *Journal of electronic imaging*, **11**, 2002, pp. 157-76, doi: 10.1117/1.1455013.