Evaluation of Gain Measurement Method for Long Antenna Using Synthetic Aperture Antenna

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1. Introduction

A cellular base station antenna has a narrow beam width in the vertical plane because the length of the antenna is more than 10 λ. While generally long distance measurements are needed to measure the antenna with high accuracy, some measurement methods in a short-range anechoic chamber have been used. The compact range method [1-2] and near-far field transformation method [3-6] are very popular. However, since additional equipment, which is large or expensive, is needed to employ these methods, it is difficult to measure the far-field pattern of an antenna compared to conventional pattern measurement methods in an anechoic chamber.

In order to overcome these problems, a far-field measurement method has been proposed for long antennas using a conventional pattern measurement system when the measurement distance is not sufficient in an anechoic chamber [7]. Since a source antenna is treated as a synthetic aperture array antenna in this method, a virtual quasi-plane wave is generated around the antenna under the test (AUT) to obtain the far-field pattern. It is found that the far-field can easily be obtained in a short range chamber without additional equipment.

In this paper, the principle of the proposed method that applies the synthetic aperture antenna technique is described to obtain the antenna gain, and experimental results are shown to clarify the validity.

2. Measurement Using Synthetic Aperture Concept

2.1 Principle of Measurement Method

The proposed measurement method obtains the far-field radiation pattern by generating a quasi-plane wave around the AUT when it is receiving a signal as shown in Fig. 1. The method can be basically thought of as having a compact range and employing a virtual synthetic aperture array antenna. However, compared to other compact range methods, the range in this method differs in that the scanning track of the virtual synthetic aperture antenna is not a parabola but a circular arc, and the quasi-plane wave can be generated in a computer. The proposed method can be generally categorized as a plane-wave synthesis method [5]. It comprises the following two procedures.

1) Actual Measurement of Field

Figure 1 shows the principle of the proposed method. When the AUT is rotated by θ_i, the received electric field, $E_{near}(\theta_i)$, from an actual element at the position of x=R is measured. Complex data (the amplitude and the phase of the field) are required to employ the vector network analyzer. Because the measurement distance, R, is not sufficiently long, the pattern of the main beam obtained from the measurement data is distorted. In this method, however, a virtual synthetic aperture array antenna can be formed by using the distorted measurement data.

2) Synthesis of Aperture Array Antenna

Virtual elements are arranged on both sides of the actual element symmetrically. The total number of elements as the synthetic aperture array antenna is 2N+1. At this time, the array antenna is configured as an arc, and the elements are arranged at equal intervals (equal angle step $\Delta\psi$). It is necessary to weight each element with the phase difference corresponding to distance $R(1-\cos\psi_j)$ in order to synthesize the plane wave in the region for the AUT (on y-axis) because the virtual scanning track is an arc. The obtained far-field value, E_{far}, can be expressed as the sum of the received electric fields, E_{near}, from all the elements at a finite distance,

$$E_{far}(\theta_i) = \sum_{j=-N}^{N} E_{near}(\theta_i + \psi_j) w_j \exp\{jkR(1-\cos\psi_j)\}\Delta\psi, \quad (1)$$

where $E_{far}(\theta_i)$, $E_{near}(\theta_i+\psi_j)$, w_j, R, ψ_j, and $\Delta\psi$ represent the desired far-field, the measured field from the element at finite distance R, the weight, the measurement distance, the relative angle of the j-th element, and the angle step, respectively. Distance $R(1\text{-}\cos\psi_j)$ represents the distance between each virtual element and the reference plane ($x=R$).

2.2 Absolute Gain Measurement

A comparison method is applied to the proposed method to obtain the absolute gain of the antenna. The standard gain antenna where the gain is defined by another method is employed to replace the AUT. The gain of the AUT, G^{AUT}, is given by

$$G^{AUT}=G^{REF}P^{AUT}/P^{REF}$$
$$=G^{REF}(E_{far}^{AUT}/E_{far}^{REF})^2, \quad (2)$$

where G^{REF}, P^{AUT}, P^{REF}, E_{far}^{AUT}, and E_{far}^{REF} are the gain of the reference antenna (REF), the power received by the AUT, the power received by the REF, the field received by the AUT, and the field received by the REF, respectively. In this method, not only the AUT but also the REF should be rotated on the turntable and measured [8].

3. Evaluation of Gain Deviation Based on Simulation

3.1 Gain Deviation Evaluation for Position Accuracy of Reference Antenna

In general, an offset from the center occurs when antennas are set on a turntable. In this case, the gain of the AUT may vary. In this section, the deviation in gain of the AUT is evaluated when the position of the REF is offset. Simulation specifications are given in Table 1. A 20-element dipole array antenna with a reflector, which is typically used in a base station, is used to evaluate the AUT. A simulation corresponding to the experiment of limited distance (R=66.7 λ) is performed using the moment method. The definitions of parameters dx, dy, and dz shown in Fig. 2 are the offsets of the parallel axis, orthogonal axis, and height axis for the actual source element direction, respectively. Figure 3 shows the deviation in gain for the three parameters. It is found that even if parameter dx has a deviation greater than that of the other two parameters, the difference in value would be only 0.1 dB in the case of a 15 cm-offset of parameter dx.

3.2 Gain Difference Evaluation for Synthetic Aperture Angle

This method virtually derives the synthetic aperture antenna so that the spread of the synthetic aperture angle may cause a difference in gain for the AUT. In this section, the difference in gain for the AUT is evaluated when the synthetic aperture angle is gradually narrowed. The evaluated antenna model is the same as that described in Section 3.1. Figure 4 shows the simulation results. The figure shows that the difference in gain is within 0.2 dB when the synthetic aperture angle is above 50 degrees.

4. Experiment in Anechoic Chamber

An experiment using an 8-GHz three-element horn array antenna is carried out in order to confirm the validity of the proposed method. The reason for using the 8-GHz antenna in this study is to be able to obtain both the actual far-field pattern and the finite distance pattern in the same anechoic chamber. The experimental specifications and antenna arrangement are shown in Table 2 and Fig. 5, respectively. A standard-gain horn antenna is set for measurement as the REF on a turntable and another horn antenna is set as the actual source element on a fixed table facing the

REF. After the initial measurement, the REF is replaced by the three-element horn array antenna with the aperture length of 11.0 λ as the AUT. In this experiment, the distance for the far-field pattern is defined as 275 λ, and that for the finite pattern is set to 55 λ, which is insufficient. All the weights, w_j, are set to 1 in the experiment. In the proposed method, the far-field pattern is generated by synthesizing the aperture array using the fields at finite distances.

Figure 6 illustrates the measurement results of the three-element horn antenna. The solid line in Fig. 6(a) indicates the field at a limited distance (R=55 λ), and the broken line is the far-field distance (R=275 λ) shown as a reference. These patterns are described in terms of the absolute gain. The gain of the main lobe in the far-field distance measurement is 21.4 dBi. The figure shows that the side lobes are distorted and the nulls are filled against the far-field distance pattern. Moreover, the gain of the main lobe in the limited distance measurement decreases by approximately 1.1 dB compared to that for the far-field distance measurement. The far-field gain synthesized by (1) is represented as the solid line in Fig. 6(b). The broken line is the absolute gain for the far-field distance measurement. The gain of the main lobe and the shape of the two patterns are obtained with high accuracy. The results indicate that the gains are in good agreement.

5. Conclusion

A gain measurement method applied to a synthetic aperture antenna and a conventional pattern measurement system was evaluated in order to obtain the gain of a long antenna. Based on the simulation results, we found that the proposed method is robust against the deviation in gain even if there is an offset in the antenna positions. Moreover, a high level of accuracy for the gain and shape of the pattern for a 11.0 λ long aperture AUT at 8 GHz were obtained from the experiment results in an anechoic chamber.

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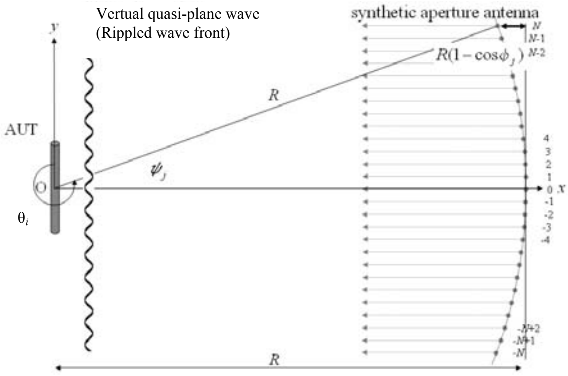


Figure 1: Principle of Proposed Method

Table 1: Simulation Specifications

Frequency	2.0 GHz
Element spacing	0.67 λ
Number of REF elements	2
Number of AUT elements	20
AUT aperture	14.0 λ
Finite distance for measurement	66.7 λ
Synthetic aperture angle	150 deg.
Number of source elements	376
Angle interval	0.4 deg.

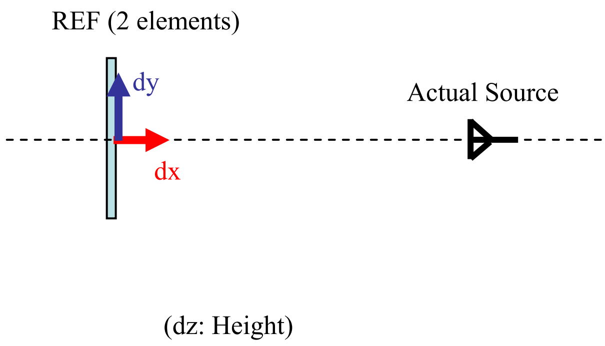


Figure 2: Definition of Position Parameter

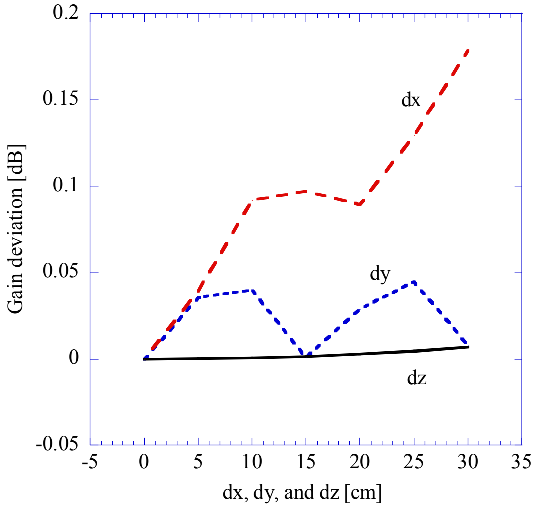


Figure 3: Gain Deviation for Position Parameters

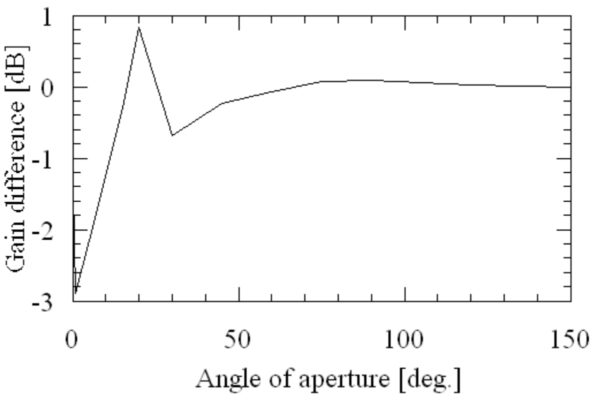


Figure 4: Gain Difference for Angle of Aperture

Table 2: Experimental Specifications

Frequency	8.25 GHz
Element	Horn antenna
Number of REF elements	1
Number of AUT elements	3
AUT aperture	11.0 λ
Finite distance for measurement	55 λ
Far-field distance for measurement	275 λ
Number of source elements	1501
Angle interval	0.1 deg.

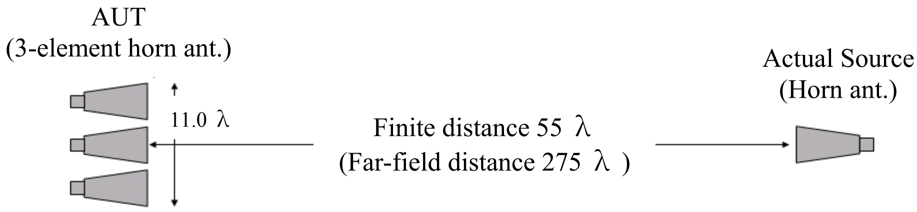
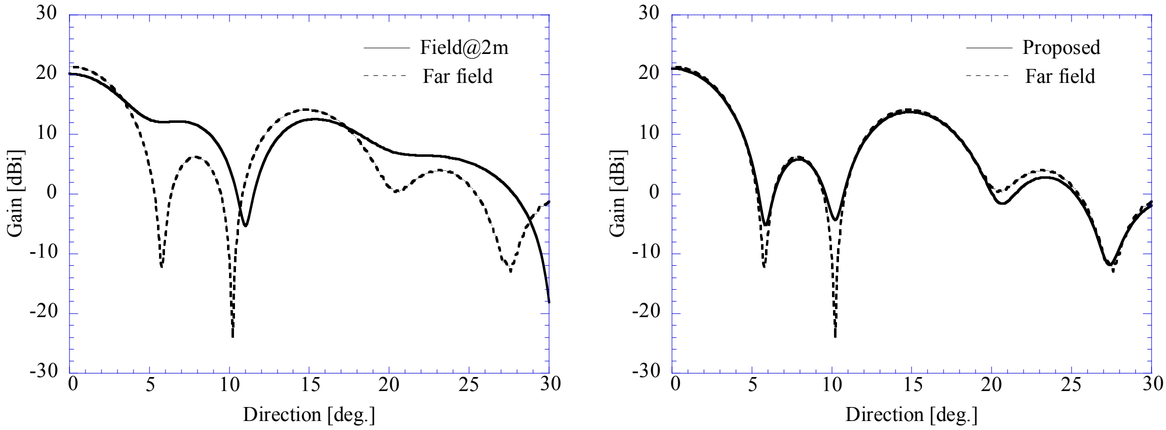


Figure 5: Arrangement of Measurement Antennas



(a) Absolute Gain of Limited Distance (b) Synthesized Absolute Gain Using Proposed Method

Figure 6: Absolute Gain of 3-Element Array Antenna