Correcting Instable Signal in Near-Field Antenna Gain Measurement

MIURA Amane and TANAKA Masato

This paper describes a technique for correcting errors caused by a signal's drift over time during a near-field antenna gain measurement. Our error correction technique is composed of the following two steps. (1) A near-field signal is corrected by using the reference signal power curve. The reference signal powers at a certain position of the probe antenna are measured during NFM for both a standard gain antenna (SGA) and the antenna under test (AUT). (2) The signal power difference between the end and start of the first antenna measurement is used to correct the signal power of the second antenna measurement. The second step is newly introduced in the paper. When a signal radiated from an offset parabolic-reflector antenna was measured twice consecutively at 28 GHz, the gain difference between the two measurements obtained using error correction techniques (1) and (2) was 0.06 dB; without error correction it was -0.24 dB; with error correction (1) only it was -0.59 dB. The measurement results at 40 GHz indicated a similar trend. The gain differences, which can be measurement errors caused by the signal drift, almost satisfied the requirement for measurement accuracy.

Keywords
Near-field antenna measurement, Antenna gain, Gain-transfer method, Signal drift, correction

1 Introduction

The gain-transfer method[1] is a simple and frequently used method of measuring antenna gain. In the gain-transfer method, the electric power in the far field of a standard gain antenna with known gain and that of an antenna under test with unknown gain are measured, and the gain of the antenna under test is obtained from the difference in electric power between the two. In this measurement, a criterion of the far-field range is given by $2D^2/\lambda$ (where D is the diameter of an antenna and λ is the wavelength)[2]. Therefore, as the frequency of the antenna under test becomes higher and the diameter becomes larger, the far-field range becomes larger and the measurement space becomes larger. In this case, near-field antenna measurement[3] is effective. Near-field antenna measurement involves obtaining antenna characteristics such as far-field radiation pattern by scanning a probe antenna two-dimensionally in the vicinity of the antenna to measure amplitude and phase of the electric field; resultant values are then used in calculations based on electromagnetic theory.

Contrary to the case of far-field antenna measurement, near-field antenna measurement is based on the assumption that most of the radiation power of the antenna is captured by the probe antenna, and hence the number of measurement points becomes large and measurement time becomes long. Therefore, amplitude and phase drift of the measurement signal becomes a problem. Consequently, in designing a measurement system, issues of amplitude and phase stability are important.

However, with increasing frequency and increasing diameter of the antenna under test, it becomes more difficult to control the amplitude and phase drift of the measurement signal. For example, as the frequency becomes higher, the wavelength becomes shorter and hence the phase drift grows larger due to the change in cable electric length. Moreover, the increase in the number of measuring points that accompanies an increase in the diameter of the antenna results in increased measuring time, hence increasing the possibility of signal drift. Therefore, near-field antenna measurement requires a technique for correcting signal drift as well as measures to increase amplitude and phase stability.

We have been investigating a technique for correcting errors caused by signal drift over time when near-field antenna measurement is employed to measure antenna gain[4]. To correct signal drift when near-field antenna measurement is performed, a method has been realized in which a signal power at a reference point is measured at fixed intervals during near-field antenna measurement of the antenna under test; near-field distribution is corrected based on the results of this measurement[5]. Therefore, when antenna gain is measured using the gain-transfer method in near-field antenna measurement, this correction method can be applied. However, when using the gain-transfer method, the measurement is performed twice (for the standard gain antenna and for the antenna under test); as a result, it is necessary to correct the electric power at the start of the second measurement using the difference in reference signal power between the start and the end of the first measurement.

This paper describes a technique for correcting errors caused by signal drift over time when antenna gain is measured using the gain-transfer method in near-field antenna measurement. Here we propose a new procedure for correcting the electric power at the start of the second measurement based on the difference in electric power between the start and the end of the first measurement, in addition to correction using the reference signal power. To verify the validity of the technique for correcting errors caused by signal drift, measurement was performed at 28 GHz and 40 GHz for an offset parabolic-reflector antenna with an effective aperture diameter of 60 cm.

2 Signal-drift correction in antenna gain measurement using near-field antenna measurement

2.1 Gain-transfer method in far-field antenna measurement

The gain-transfer method[1] in far-field antenna measurement is a method of obtaining the gain of the antenna under test by measuring the ratio of peak power of the antenna under test to that of an antenna with known gain (standard gain antenna). A conceptual diagram is shown in Fig.1. A radio wave is emitted from a transmitting antenna connected to a transmitter SG with a gain value of G_T. A standard gain antenna and the antenna under test are both placed at a distance R from the transmitting antenna, such that $R>2D^2/\lambda$; where D is an antenna diameter and λ is the wavelength. The standard gain antenna is connected to a receiver R_X and a received power P_S is measured. Next, the antenna under test is connected to the receiver R_X and the attenuation α of a calibrated variable attenuator is adjusted so that the received power P_A becomes equal to P_S. At this time, the gain G_A of the antenna under test is given by the following formula (1) in dB notation.

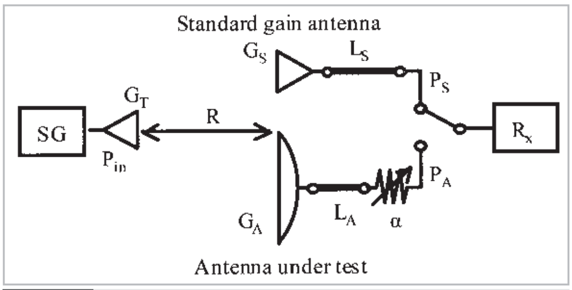

Fig.1 *Antenna gain measurement using the gain-transfer method (far-field antenna measurement)*

$$[G_A]dB = [G_S]dB - [L_A]dB + [L_S]dB + [\alpha]dB, \quad (1)$$

Where G_S is the gain of the standard gain antenna, and L_A and L_B are losses of cables. This formula describes the basis of the gain measuring method. If the linearity of the receiver is ensured, the gain can be obtained by finding the difference between readings P_A, P_S of the receiver following the formula (2) below without using the variable attenuator.

$$[G_A]dB = [G_S]dB - [L_A]dB + [L_S]dB + [P_A]dB - [P_S]dB \cdots\cdots (2)$$

2.2 Signal drift in near-field antenna measurement and a new technique for correcting errors caused by signal drift

An antenna gain measuring method using the gain-transfer method in the case of near-field antenna measurement is shown in Fig.2. In near-field antenna measurement, a far-field distribution is obtained by performing near- to far-field transformation on a near-field distribution obtained by scanning the probe antenna. The peak powers P_A', P_S' of this far-field distribution correspond to the readings P_A, P_S of the receiver in far-field antenna measurement using the gain-transfer method. If the signal power drifts during measurement, an error may occur in the far-field peak power. Fig.3 is a schematic diagram of the signal drift. The horizontal axis denotes time and the vertical axis denotes the near-field signal power, assuming that the probe antenna position is fixed to a reference point (for example, a reference point in front of an antenna, where signal intensity is large). Measurement 1 represents measurement of the standard gain antenna and measurement 2 represents measurement of the antenna under test. In order to correct a curve with drift (solid line) to obtain a curve without drift (dotted line), correction consisting of the following two steps is required.

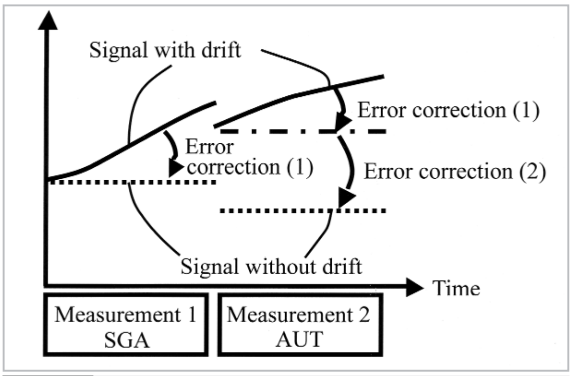

Fig.3 *Schematic diagram of signal drift in measurement of antenna gain employing the near-field antenna measurement*

(1) Correction of the near-field distribution in each measurement
(2) Correction of the electric power at the start of Measurement 2 based on signal power drift in Measurement 1

A procedure is described below for measuring the antenna gain using both the gain-transfer method and the above-mentioned two-step correction together in near-field antenna measurement.

(a) Near-field antenna measurement is performed consecutively for the standard gain antenna and for the antenna under test. During this step in measurement, the reference signal power is measured at fixed intervals to prepare a characteristic curve of the reference signal power. The measured near-field signal power distribution is corrected using this characteristic curve (Correction (1)). The far-field distribution is obtained by the near- to far-field transformation for the standard gain antenna and the antenna under test to find the peak powers for the two antennas P_S', P_A', respectively.

(b) The difference in reference signal power P_D between the end and the start of measurement 1 is obtained (calculation of the amount of correction for Correction (2)).

(c) The antenna gain is obtained by the following formula.

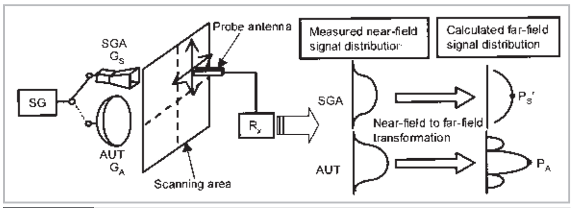

Fig.2 *Antenna gain measurement using the gain-transfer method (near-field antenna measurement)*

$[G_A]dB = [G_S]dB - [L_A]dB + [L_S]dB + [P_A']dB - [P_D]dB - [P_S']dB$ ··(3)

Correction (1) has been proposed in reference[4] and has already been put to practical use. In this paper, we introduce Correction (2).

2.3 Measurement

When measuring the antenna gain using the gain-transfer method, the following factors leading to error can be considered in addition to the signal drift.

- Error in the antenna gain of a standard antenna

Difference between calibration data and actual gain is suspected to be due to dirt on or deformation of the antenna.

- Errors resulting from differences between the standard gain antenna and the antenna under test

Two antennas are suspected to feature different values of mismatched polarization between the transmitting and the receiving antenna and different values of mismatched impedance between the receiver and the receiving antenna.

The purpose of this research is to verify the effect of signal drift correction. In order to minimize any factors leading to error other than signal drift, we decided not to use the standard gain antenna in the experiment. Measurement was performed twice consecutively for the same antenna under test, to check whether the gain difference between the two measurements was zero; that is, to check whether the gains were equal for the two measurements. Evaluation of the gain difference was performed for each of the following three cases with correction.

(a) Without any correction
(b) With Correction (1)
(c) With both Correction (1) and Correction (2)

Note that the relation $L_A = L_S$ is obtained in formula (3) bacause the cable is the same for two measurements. Measurement conditions are shown in Table 1. The antenna used in the measurement was an offset parabolic-reflector antenna (effective aperture diameter: 60 cm) having a specular surface made of aluminum; the primary radiator was a circular-polarization-wave antenna. The near-field antenna measurement device used was one capable of planar scan for a plane of 1.8 m × 1.8 m (300 V－6×6, Nearfield Systems, Inc.) installed in an electromagnetic anechoic chamber of a facility for studying satellite communication radio waves[6] within the Kashima Space Research Center of the Communications Research Laboratory. The near-field antenna measurement device and the antenna under test (AUT) used in the experiment are shown in Fig.4. Measuring frequencies were 28 GHz and 40 GHz. For the reference point(s) used for correction of the reference signal power, several arrangements of reference points were considered, including a single reference point where the signal intensity was large. In this experiment, in one such arrangement, four points at the corners of a 20 cm × 20 cm square whose center coincided with the center of the scan were selected as

Table 1 *Measurement conditions*

Antenna Under Test (AUT)	
Antenna type	Offset parabolic reflector
Aperture diameter	60 cm φ
Primary radiator	Spiral antenna (RHCP)
Near-field measurement parameters	
Target frequencies	28 GHz, 40 GHz
Scanning measure	Planar scan
Scanning area	W1.2 m×H1.3 m
Sampling points	238×251 in 28 GHz 339×359 in 40 GHz
Radiator-to-probe distance	28 cm
Distance between sampling points	<0.5 λ
Avegaging number	64/sampling point
Scanning time	128 min. in 28 GHz 252 min. in 40 GHz
Measurement of reference signal curve	
Reference position	4 apexes of a square Length of each side= 20 cm Center of the square=scan center
Interval between reference signal measurement	180 sec.

reference points, and values at the reference points were averaged. The reference points were measured in a 180-second cycle.

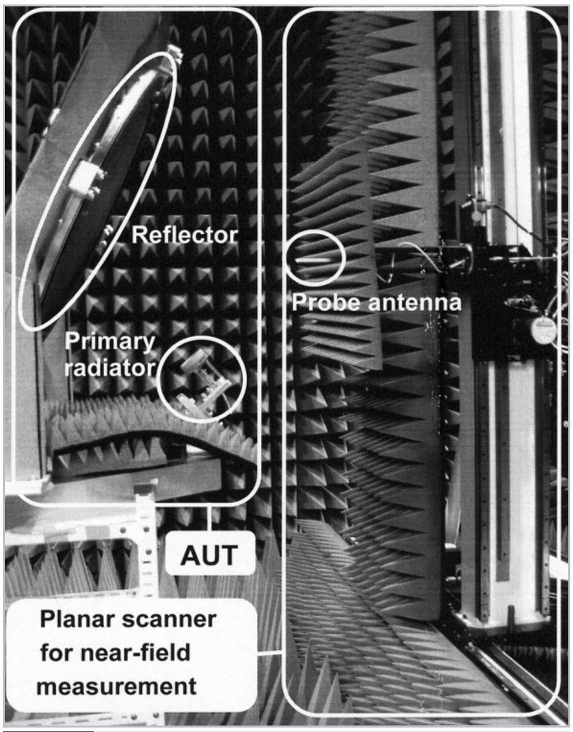

Fig.4 Appearance of the measuring system

Amplitude characteristic curves of the reference signal measured at 28 GHz and at 40 GHz are shown in Fig.5 and Fig.6, respectively. Amplitude variation of the signal power was 0.65 dBp-p for Measurement 1 and 0.38 dBp-p for Measurement 2 in the case of 28 GHz, and 1.66 dBp-p for Measurement 1 and 0.22 dBp-p for Measurement 2 in the case of 40 GHz. Moreover, the phase characteristic curves of the reference signal at 28 GHz and at 40 GHz are shown in Fig.7 and Fig.8, respectively. Phase variation at 28 GHz was 31.5˚p-p for Measurement 1 and 13.3˚p-p for Measurement 2, and was 137.9˚p-p for Measurement 1 and 19.9˚p-p for Measurement 2. From the above results, we concluded that correction of the near-field distribution using a reference signal power curve was essential for each measurement. Fig.9 shows the differences in near-field amplitude/phase distributions before and after correction using the reference signal power curve in a 3-dimensional representation for the first measurement at 28 GHz. Fig.9(a) shows the difference between the amplitude distributions; Fig.9(b) shows the difference between the phase distributions. In the figures, the X-axis and Y-axis show horizontal position and vertical position of a scanning area, respectively, and the vertical axis shows the difference in amplitude or phase of the electric field. In order to make the figures easier to read, data is thinned out at intervals of five points. Part of the 3-dimensional representation of Fig.9(b) is deleted; this is because when the phase takes different values having opposite signs in the vicinity of 180˚(or -180˚) in the phase distributions before and after correction, the phase difference becomes large, rendering the figure rather complicated to understand; phase differences at these positions were thus not shown. From Fig.9, differences were observed between the amplitudes and between the phases, respectively, before and after correction. Furthermore, in order to determine the effect of the correction of the near-field distribution on the far-field distribution, the difference between the peak powers in the far-field distributions before and after correction was obtained for each measurement. The results are shown in Table 2. The peak powers showed differences ranging from 0.16 dB to 2.97 dB before and after correction. This indicates the effect of the reference signal power on the correction. In addition, the difference in peak power in Measurement 1 at 40 GHz, which was 2.97 dB, was large relative to other measurements. This is believed to be due to amplitude variation of approximately 1.2 dBp-p in a period of 60-160 minutes in the amplitude characteristic curve of reference signal power (Fig.6(a)). It is thought that in cases in which correction by the reference signal power is large, particularly large signal drift will be seen, as here.

On the other hand, the signal power difference P_D between the start and end of Measurement 1 was -0.65 dB in the case of 28 GHz and -1.29 dB in the case of 40 GHz, respectively, as seen in Fig.5 and Fig.6. Therefore, it was expected that electric power at the start of

Measurement 2 required correction.

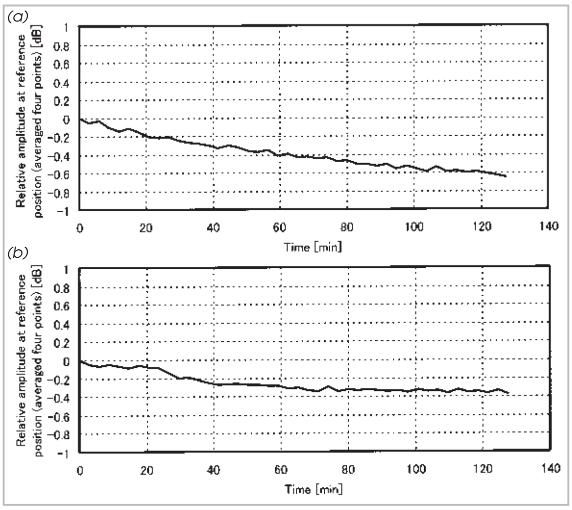

Fig.5 Amplitude characteristic curve of reference signal power (28 GHz).(a) Measurement 1, (b) Measurement 2

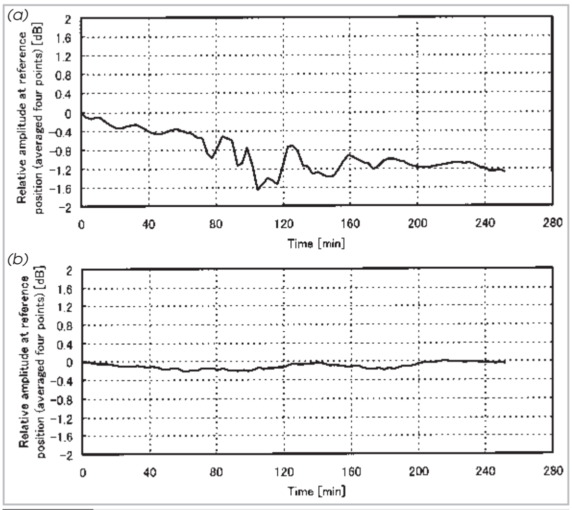

Fig.6 Amplitude characteristic curve of reference signal power (40 GHz).(a) Measurement 1, (b) Measurement 2

Table 2 Difference in far-field peak power before and after correction using the reference signal power curve

Frequency	Measurement no.1	Measurement no.2
28 GHz	0.63 dB	0.29 dB
40 GHz	2.97 dB	0.16 dB

The gain differences between the first and second measurements for three cases are shown in Fig.10. In the case of 28 GHz, the gain difference without any correction was -

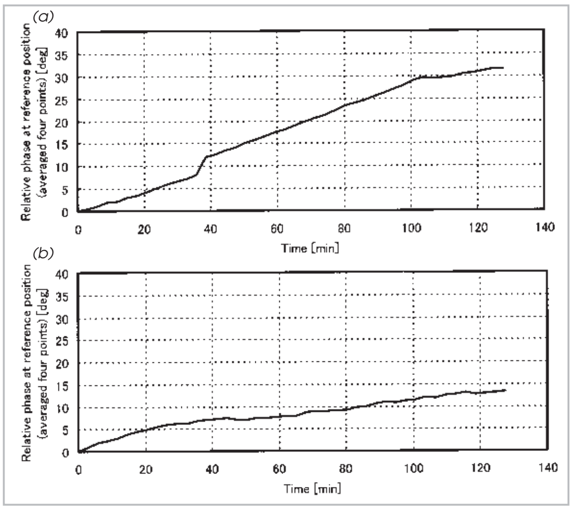

Fig.7 Phase characteristic curve of reference signal power (28 GHz).(a) Measurement 1, (b) Measurement 2

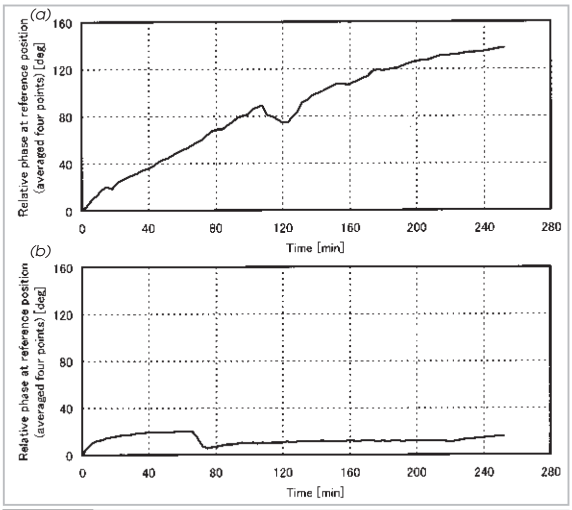

Fig.8 Phase characteristic curve of reference signal power (40 GHz).(a) Measurement 1, (b) Measurement 2

0.24 dB and that with Correction (1) alone was -0.59 dB, whereas it was reduced to 0.06 dB when Correction (1) and Correction (2) were used together. This can be interpreted as follows. In Correction (1) near-field distributions for Measurement 1 and Measurement 2 were corrected by using the signal powers at the starting points of Measurement 1 and Measurement 2, respectively, as a reference. However, there is a difference between the signal powers at the starting points of Measurement 1 and Measurement 2. Thus a gain difference remained although the respective near-field distributions were corrected. The gain differ-

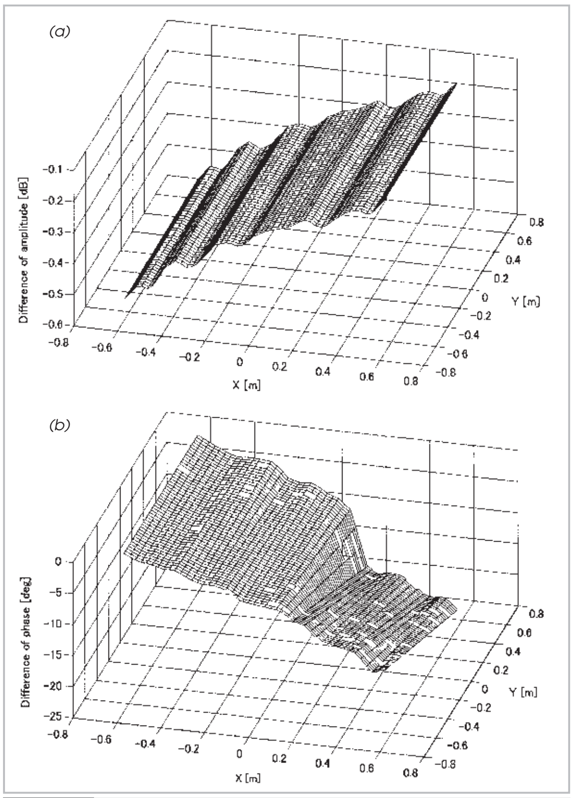

Fig.9 Difference in near-field distribution before and after correction using the reference signal power curve (at 28 GHz, in Measurement 1).(a) Difference in amplitude distribution (b) Difference in phase distribution

ence between the two measurements was able to be reduced by correcting the signal power at the start of Measurement 2, thereby matching the signal levels at the starting points of Measurements 1 and 2. This trend was similarly observed at 40 GHz as well. That is, the gain difference without any correction was 1.69 dB and that with only Correction (1) was -1.12 dB, both of which values were larger than those in the case of 28 GHz; however, the gain difference was reduced to 0.17 dB through the joint use of the two corrections.

2.4 Discussion

The Communications Research Laboratory is proposing a large deployable antenna onboard the Quasi-Zenith satellite[7], in which a metal mesh is used as a reflecting surface of the antenna. As part of measurement of the electrical properties of this mesh in the Ka band, the gain difference was evaluated between a parabolic antenna made of GFRP

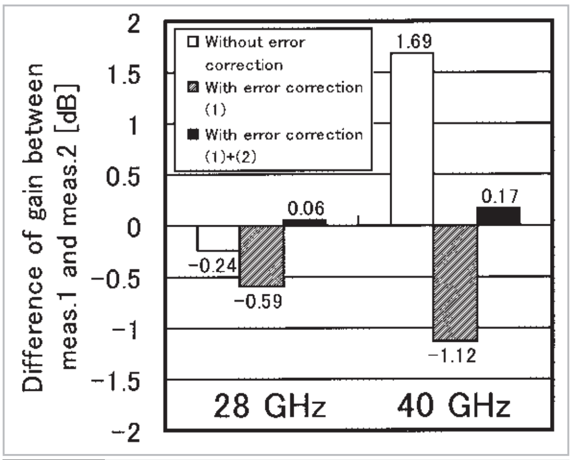

Fig.10 Comparison of measurement results

(Glass Fiber Reinforced Plastic) with an attached mesh and a parabolic antenna with specular surface made of aluminum[8]. At that time, the measurement accuracy target was set to about 0.1 dB. As a result of the correction of errors caused by signal drift described in this paper, the gain difference between two measurements (in other words, the measurement error due to signal drift) was 0.06 dB for 28 GHz and 0.17 dB for 40 GHz. Therefore, the target measurement accuracy has been nearly achieved, although factors leading to error other than signal drift must be considered.

Possible causes of the signal drift that may occur during the measurement include: variation in phase accompanying a change in the electric length of the cable due to temperature change of the measurement environment; operation characteristics of the receiver[9]. Possible measures for controlling signal drift include: use of a cable featuring small phase variation and small loss variation; keeping the temperature of the measurement environment constant; using the receiver in its stable state (i.e., avoiding using it in its transient state just after being switched on). In designing the measurement system, amplitude and phase stability must be ensured through measures such as these. Signal drift can be corrected further, using the technique described in this paper. We believe that this technique will prove effective, especially when signal drift affects measurement accuracy due to high target frequency or long measurement time.

3 Conclusions

When performing antenna gain measurement using near-field antenna measurement and the gain-transfer method, amplitude and phase drifts of the measurement signal pose problems. This paper examined a technique for correcting errors caused by this signal drift. The technique examined uses a two-step procedure: one step for correcting the near-field distribution using reference signal power and another for correcting the electric power at the start of the second measurement based on the difference in reference signal power between the start and the end of the first measurement. In this paper, we introduced the latter procedure. To verify the effect of signal drift correction, an offset parabolic-reflector antenna with an effective aperture diameter of 60 cm was measured twice consecutively to evaluate gain difference. In the case of 28 GHz, the gain difference without any correction was -0.24 dB, and that with only the reference signal power correction was -0.59 dB, whereas it was 0.06 dB with both the reference signal power correction and the correction of the electric power difference, the smallest value seen. The measurement results at 40 GHz also indicated a similar trend. The measurement error caused by signal drift was found to nearly satisfy the 0.1-dB measurement accuracy target. The results described above thus verify the effectiveness of our proposed technique of correcting errors caused by signal drift.

References

1 G. E. Evans, "Antenna Measurement Techniques", Artech House, Boston, 1990.

2 IEICE, "Antenna Engineering Handbook", Ohmsha, 1980. (in Japanese)

3 D. Slater, "Near-Field Antenna Measurements", Artech House, Boston, 1991.

4 A. Miura and M. Tanaka, "A Technique to Correct Instable Signal in Near-Field Antenna Gain Measurement", Technical Report of IEICE, 2002, 25-28, AP2002-60. (in Japanese)

5 D. Slater, "A 550-GHz Near-Field Antenna Measurement System for the NASA Submillimeter Wave Astronomy Satellite", Antenna Measurement Techniques Association Conference, Oct. 1994.

6 K. Iigusa, M. Tanaka, and H. Wakana, "Facility for Studying Satellite Communications Radio Waves", Review of The Communications Research Laboratory, 1999, 181-192, Vol. 45, No. 3/4. (in Japanese)

7 M. Tanaka, A. Miura, M. Yoshihara, S. Iikura, K. Uchimaru, T. Sato, and Y. Tsukumo, "Research of Deployment Mechanism for the Large Deployable Reflector for the Mobile Satellite Communication System", Proceedings of the 46th Space Sciences and Technology Conference, 2002, 1178-1181, 3C18. (in Japanese)

8 A. Miura and M. Tanaka, "Electrical Characteristics of Mesh Reflecting Surface for Mobile Communications and Broadcasting Satellite's Large Deployable Antenna", Proceedings of the 46th Space Sciences and Technology Conference, 2002, 1132-1137, 3C9. (in Japanese)

9 K. Iigusa, Y. Hori, and J. R. Schmidt, "Error Factors of A Near-Field Antenna Measurement System and The Improvement of Its Measurement Accuracy", Review of The Communications Research Laboratory, 1993, 23-36, Vol. 39, No. 1. (in Japanese)

***MIURA Amane**, Ph. D.*

Researcher, Mobile Satellite Communications Group, Wireless Communications Division

Antenna, Satellite Communications

***TANAKA Masato**, Dr. Eng.*

Senior Researcher, New CRL Promotion Office

Antenna, Satellite Communications