Mobile Terminal Antenna | Overall Radio Performance Evaluation | Efficient Evaluation

Technology Reports

Antenna Measurement System for Mobile Terminals

We have developed an antenna measurement system for mobile terminals that can efficiently evaluate both the performance of the mobile terminal antenna itself and the overall radio performance of the mobile terminal. We provide an overview of that measurement system and describe the technology applied for faster and more accurate measurement as well as the effectiveness of that technology.

Yoshiki Okano and Keizo Cho

1. Introduction

The mobile terminal antenna is one of the essential elements that affects quality in a mobile communication network. In recent years, there has been increasing need for more accurate evaluation of the performance of mobile terminal antennas under actual use conditions such as in speech/data mode conditions as well as in the free-space condition. In addition, the latest mobile terminals must operate in multiple bands to enhance the radio network capacity and provide wide coverage area with diversification of functions [1], so antenna performance must also be evaluated in multiple bands. Furthermore, demand for higher speed and quality in the wireless transmission section has motivated active study on the application of receive antenna diversity and Multiple Input Multiple Output (MIMO)*1 transmission [2][3], so the importance of performance evaluation for mobile terminals equipped with multiple antennas is also increasing. Thus, the number of evaluation items for antenna performance is increasing and efficient measurement is also becoming an important issue.

On the other hand, there has been vigorous discussion of overall radio performance evaluation methods for mobile terminals by the Cellular Telecommunications & Internet Association (CTIA) and the 3rd Generation Partnership Project (3GPP) [4][5]. Those efforts include the specification of methodology for assessing the overall radio performance of the mobile terminal in active mode, including the radio circuit as well as the antenna. Accordingly, a measurement environment that can be used for evaluation of both the performance of the antenna itself and the overall radio performance of the mobile terminal is needed for the development of mobile terminals. With that motivation, we developed a mobile terminal antenna measurement system that allows both evaluation of the antenna performance and the overall radio performance of the mobile terminal with high speed and high accuracy.

In this article, we first briefly describe the issues in the evaluation of mobile terminal antenna performance and the overall radio performance. We then introduce the newly developed measurement system overview and the measurement technology for higher speed and accuracy that is adopted for the system.

2. Issues in Mobile Terminal Antenna Evaluation

2.1 Issues in Antenna Performance Evaluation

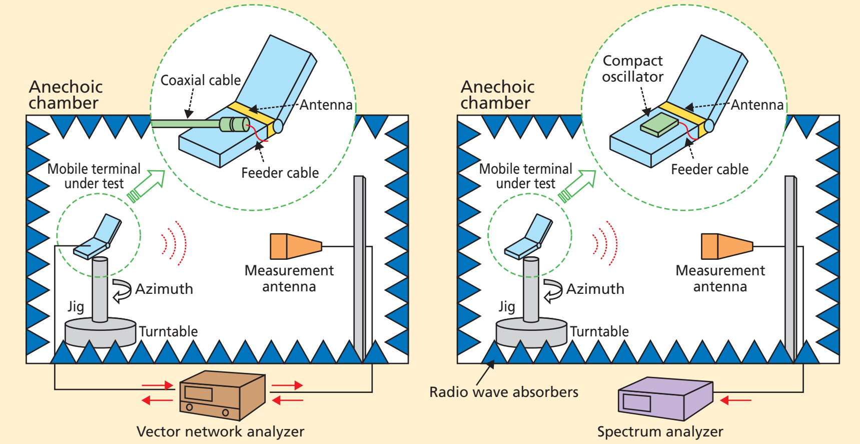
To evaluate the performance of a mobile terminal antenna, it is basically necessary to measure how much power the antenna actually radiates. The radiation pattern is the basis for determining the radiation efficiency, which represents the ratio of the radiated power to the input power for the antenna. In the case of application to a multi-antenna configuration for diversity or MIMO transmissions, an important criterion called the spatial correlation coefficient*2 between antennas is obtained [6].

The basic configuration of a system

*1 **MIMO**: Wireless communication technology for expanding the transmission capacity by using multiple transmit/receive antennas.

*2 **Spatial correlation coefficient**: An indicator of the correlation between two antennas. The smaller the coefficient, the greater the extent to which the two antennas can receive independent signals.

for measuring radiation patterns involves placing the mobile terminal that is under test on a turntable in an anechoic chamber at the same height as a measurement antenna (**Figure 1**). The mobile terminal is rotated in the azimuth[*3] direction as the measurement antenna either transmits or receives a signal for measurement. The radiation efficiency or spatial correlation coefficient is derived from the radiation patterns measured for multiple planes. The measurement methodology is described in detail in Section 2.2.



(a) Vector network analyzer measurement system (b) Measurement system with compact oscillator and spectrum analyzer

Figure 1 Basic antenna measurement system

The antenna measurement system adopts either of two approaches, the vector network analyzer method (Fig. 1(a)) or a method in which the signal from a compact oscillator placed on the mobile terminal is received by a spectrum analyzer (Fig. 1(b)). In the vector network analyzer method, the signal from the output port of the vector network analyzer is connected by a cable to either the antenna under test or the measurement antenna and the input port is connected to the other antenna. The vector network analyzer system can split the transmission signal from the output port and get feedback as a reference signal to the input port for comparison with the measured signal, so by continually monitoring the output power, highly accurate antenna measurement without the effects of fluctuation in output power can be achieved. The phase characteristics can also be measured in the same way on the basis of the reference signal, so the spatial correlation coefficient between antennas can also be evaluated. The frequency sweeping function[*4] also allows easy changing of the measurement frequency, so performance measurements at multiple frequencies can be obtained at one time, and the differences in antenna performance for different frequencies such as the transmit/receive bands or the various communication channels within each band can also be evaluated efficiently. Nevertheless, this measurement method requires a long coaxial feeder cable to be connected to the antenna of the mobile terminal under test, and the effects of spurious radiation from the coaxial feeder cable degrade measurement accuracy. Accordingly, placement of the coaxial feeder cable and other related factors must be fully considered in the evaluation of antenna performance.

The method that uses a compact oscillator and spectrum analyzer, on the other hand, does not require a long coaxial feeder cable to the antenna under test, so there is no spurious radiation from the cable and highly accurate measurement can be attained. Nevertheless, the compact oscillator generally used in this measurement method cannot switch among measurement frequencies instantly, so multi-frequency measurement requires repetition of the same measurement sequence over and over. Furthermore, to prevent the compact oscillator itself from influencing the measurement results, the oscillator must be driven by an extremely small battery. That requires frequent battery replacement, which reduces measurement efficiency and measurement accuracy may also decline because of fluctuations in output power due to battery drain because the output power cannot be monitored. In addition, the compact signal generator and spectrum analyzer method does not adopt a reference signal as does the vector network analyzer, so the phase characteristics of the antenna cannot be measured.

An issue that is common to both methods is the need to use non-metallic

*3 **Azimuth**: The longitude direction of rotation in the two-axis positioner.

*4 **Frequency sweeping function**: A measuring instrument function that varies the measurement frequency at a constant rate within a particular range.

materials for the jig and the positioning device that holds the mobile terminal to prevent effects on the measurement results. However, there are issues in achieving sufficient strength and implementation of the rotation mechanism when non-metallic materials are used, so these must be given due consideration.

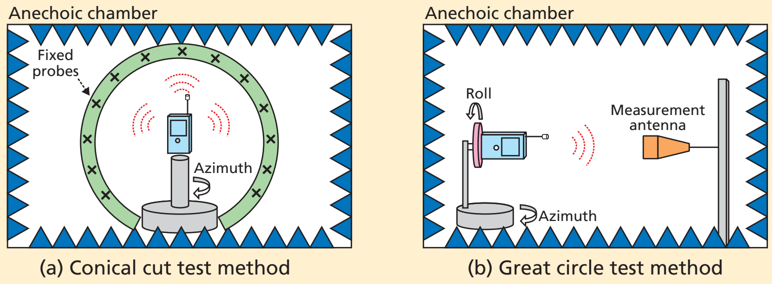


Figure 2 Measurement method for the overall radio performance of the mobile terminal

2.2 Issues in Evaluation of Mobile Terminal Overall Radio Performance

For the overall radio performance of a mobile terminal in active mode, CTIA and 3GPP have specified two evaluation criteria. One is the Total Radiated Power (TRP), which is defined as the integral of the power transmitted in different directions over the entire radiation sphere; the other is the Total Isotropic Sensitivity (TIS), which is defined using the effective isotropic sensitivity, which represents the power available at the antenna output such that the sensitivity threshold is achieved [4][5]. The methodologies for measuring these criteria are broadly classified into the conical cut test methods (**Figure 2**(a)) and the great circle test methods (Fig. 2(b)), which differ in scanning methods. The conical cut test method uses probes that transmit or receive the signal (multiple fixed probes or a single movable probe) arranged in a vertical plane as shown in Fig. 2(a) and the transmitted/received power are measured as the mobile terminal under test is rotated in the azimuth direction. In particular, fast three-dimensional measurement can be achieved by electrical switching among multiple fixed probes. Also, the mobile terminal under test is only rotated in the azimuth direction, so three-dimensional measurement is possible even with a heavy full-body phantom placed near the mobile terminal. This method, however, has the issue of the multiple fixed probes, the large arch structure for supporting them, and the complex cabling for connecting the various probes and measurement instruments affecting the measurement results.

In the great circle test method, on the other hand, the measurement antenna is fixed in position and the mobile terminal under test is rotated in both the azimuth and the roll*5 direction to achieve three-dimensional measurement, as shown in Fig. 2(b). The great circle test method does not require the large and complicated probe system used by the conical cut test method, so it is highly compatible with ordinary antenna measurement systems and highly-accurate measurement can be expected. On the downside, two axes of rotation must be set up so that the mobile terminal under test can be rotated in three dimensions. That places certain restrictions on the weight of mobile terminal under test and any objects placed next to it. This method also involves more measurement time than the conical cut test method.

3. Developed Antenna Measurement System for Mobile Terminals

3.1 Overview

The development of the mobile terminal antenna measurement system was guided by the following policy.

- Allow efficient measurement of characteristics for multiple frequencies and multiple antennas.
- Allow evaluation of both the antenna performance itself and the overall radio performance of the mobile terminal.

For evaluating the performance of the antenna itself, we adopted the vector network analyzer measurement system to avoid the effects of fluctuations in the output power, to be able to obtain the phase characteristics, and for ease in switching the measurement frequency, as described in Chapter 2. For evaluating the overall radio performance of the mobile terminal, we adopted the great circle test method for high measurement accuracy.

The configuration of the developed mobile terminal antenna measurement

*5 **Roll**: The latitudinal direction of rotation in the two-axis positioner.

system is shown in **Figure 3**. A positioning device that provides two-axis rotation and a measurement antenna that is equipped with a polarization switching mechanism are placed in an anechoic chamber. The vector network analyzer required for evaluating the performance of the antenna itself and the radio communication tester required for evaluating the overall radio performance of the mobile terminal are placed outside the anechoic chamber. All of the equipment that constitutes this measurement system is mutually-connected by a General Purpose Interface Bus (GPIB). Both the performance evaluation of the antenna and the overall radio performance evaluation of the mobile terminal are performed fully automatically by software installed on a control PC. For the performance evaluation of the antenna itself, the vector network analyzer serves as the signal source and the receiver for measuring the antenna radiation patterns; for overall radio performance evaluation of the mobile terminal, the radio communication tester serves as the base station simulator and the transmit/receive power is measured by configuring the mobile terminal under test that is in the anechoic chamber in loopback mode. This configuration allows for easy switching between the vector network analyzer and the radio communication tester, so evaluation of antenna performance and overall radio performance of the mobile terminal can both be accomplished without changing the testing configuration inside the anechoic chamber. In general, changing the positions of the radio wave absorbers, the jig and the positioning device inside the anechoic chamber introduces the possibility of affecting measurement accuracy, so the ability to perform two types of antenna performance evaluation without changing the physical configuration in the anechoic chamber contributes greatly to measurement accuracy.

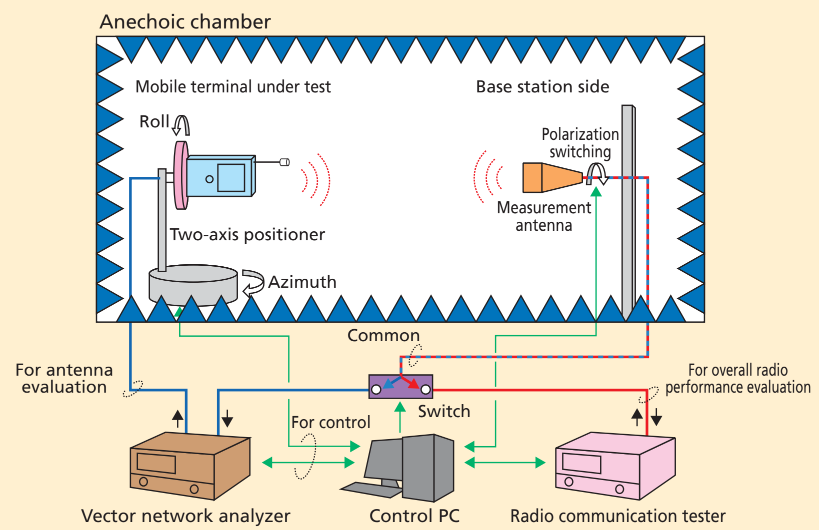


Figure 3 Configuration of the mobile terminal antenna measurement system

3.2 Improvements in Measurement for Higher Speed and Accuracy

To achieve faster and more accurate measurement, we implemented improvements concerning the structure of the device positioner, the feeding technique to the antenna under test and the rotation method for the mobile terminal under test. Those improvements are described below.

1) Non-metallic Two-axis Positioner

The device positioner we developed for this measurement system is shown in **Figure 4**. To avert degradation of measurement accuracy by reflection of the electromagnetic field emitted from the antenna by jigs close to the mobile terminal under test, this mechanism is made entirely of non-metallic material except for the roll-axis rotation motor unit. The non-metallic material has a low relative permittivity[*6] of from 1 to 4. The roll-axis rotation motor unit, which contains metal, is placed on the lower part of the turntable, sufficiently far from the mobile terminal under test to minimize the degradation of measurement accuracy. The construction of only low-permittivity non-

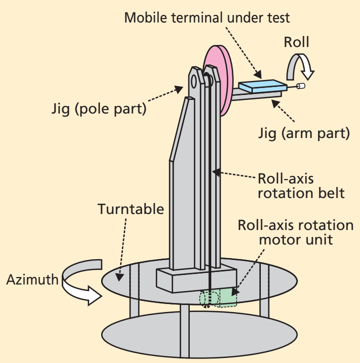


Figure 4 Two-axis positioner structure

*6 **Relative permittivity**: The ratio of the electric flux density and the electric field is defined as the permittivity. When comparing the permittivity of materials, the permittivity relative to a vacuum is generally used.

metallic material also allows fast rotation rates of 6 rpm (rounds per minute) for azimuth and 20 rpm for roll while maintaining a stopping angle of within 1°, thus achieving three-dimensional performance evaluation of terminal antennas that is both fast and accurate.

2) Application of Optical Fiber Cable Feeding System

Concerning the performance evaluation of the antenna itself, spurious radiation from the coaxial feeder cable to the antenna under test may degrade measurement accuracy, as described in Chapter 2. To avoid this issue, this measurement system adopts an optical fiber cable and electro-optical converter to feed the antenna under test in place of the coaxial cable (**Figure 5**). The electrical signal that is output by the vector network analyzer is converted to an optical signal by a laser diode module that is placed outside the anechoic chamber and transmitted via the optical fiber cable to a small photodiode module placed at the mobile terminal under test. There, the optical signal is converted back to an electrical signal that is applied to the antenna via a very short coaxial cable. Because there is no spurious radiation from the optical fiber cable, great improvement in measurement accuracy is obtained by elimination of the degradation caused by the coaxial feeder cable. Furthermore, for multi-antenna measurement, a photodiode module can be set up for each antenna element and connected to the vector network analyzer by the optical fiber cable and a high-speed coaxial switch. The measurement software that is installed on the control PC used as the controller conducts the measurements automatically while switching the feeder cables at high speed, thus evaluating the performance of multiple antennas concurrently with rotation of the turntable. This measurement system has a high-speed Single-Pole-Four-Throw (SP4T) coaxial switch, so simultaneous multi-antenna measurement for up to four elements is possible [7].

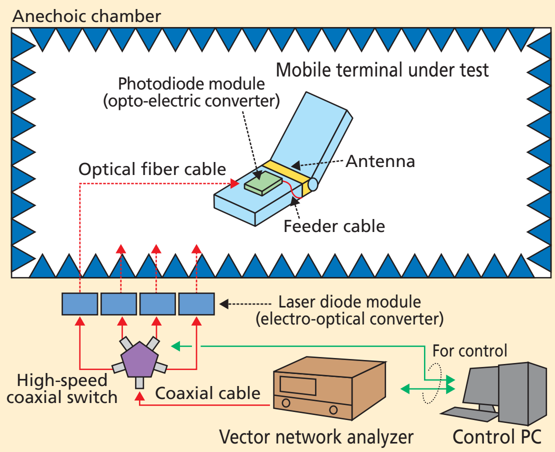


Figure 5 Electro-optical converter for antenna feed by optical fiber cable

3) Two-axis Simultaneous Rotation Measurements

In evaluating the overall radio performance of a mobile terminal, it is concluded that a 15° or less sample grid*7 in both azimuth and elevation is sufficient for accurate measurements of the TRP (a criterion of transmitter performance) [4][5]. When measuring the transmitted power in all directions over the entire sphere, the most basic measurement method is one-axis rotation, in which measurements are taken while rotating the device in the azimuth direction for a fixed angle in the roll direction, and then changing the roll direction angle and repeating the measurement procedure. In that case, measurement cannot be done while rotating in the roll direction. It is therefore necessary to return to the initial azimuth direction, so much time is required to finish the total measurements. This measurement system adopts two-axis simultaneous rotation, in which the increase in measurement time due to control of the rotation mechanism is greatly reduced by controlling simultaneous rotation in two directions (azimuth and roll) during measurement.

4. Speed and Accuracy Effects

4.1 Accuracy of Radiation Pattern and Radiation Efficiency Measurements

To verify the measurement accuracy with respect to the two-axis positioner device and optical fiber cable feeding system adopted for this measurement system, a standard dipole antenna*8, which is the most basic antenna configuration, is placed near the two-axis positioner for

*7 **Grid**: In this article, the 3-D measurement points used.

*8 **Dipole antenna**: The simplest of all antennas, comprising two straight, linearly-aligned conductor wires (elements) attached to the end of a cable (feed point).

measurement of the radiation patterns when an optical fiber cable feeding system is used. The placement of the standard dipole antenna is shown in **Photo 1**. The distance between the jig (pole) and the antenna is about 200 mm, which is approximately 1.5 wavelengths in the 2 GHz band. The maximum gain and the radiation efficiency, which is derived from the far-field pattern integration methodology[*9][8], of the standard dipole antenna measured with this system are shown in **Table 1**. The measurement frequency bands are the 800 MHz band and the 2 GHz band, and the values are normalized by the values obtained in free space without the two-axis positioner device. From Table 1 we can see that the maximum gain and radiation efficiency error is within ±0.1 dB for both 800 MHz and 2 GHz. We can also see that when the two-axis positioner device is placed near the antenna under test, too, the antenna characteristics can be evaluated with the same accuracy as in free space. The radiation pattern in the 2 GHz band is shown in **Figure 6**. For comparison, the calculated results for a half-wavelength dipole antenna in free space and the measured results with a conventional coaxial feeder cable are shown. The data in Fig. 6 confirms that the measurement results obtained by this system agree well with the results of the numerical calculations, and that most of the distortion in the radiation patterns for the co-polarized component caused by the coaxial cable is eliminated. The cross-polarized component[*10], which does not exist in the calculations that agree with theory, is improved approximately 10 dB compared to when the conventional coaxial cable is used. Suppression to a level of –20 dB from the co-polarized component is thus achieved. Those results show that this system achieves a high measurement accuracy equivalent to free space with the two-axis positioner device in place. The results also show that a great improvement in measurement accuracy can be attained by using optical fiber cable feeding system.

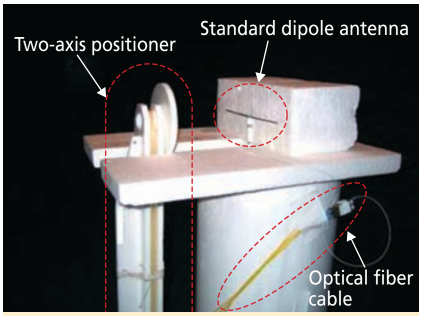


Photo 1 Standard dipole antenna arrangement for verifying measurement accuracy

Table 1 Maximum gain and radiation efficiency of a standard dipole antenna

	Maximum gain (dB)	Radiation efficiency (dB)
800 MHz	0.0	–0.1
2 GHz	0.0	–0.1

4.2 Accuracy of Spatial Correlation Coefficient Measurements

To verify the accuracy of measuring the spatial correlation coefficient between antennas, we calculated the spatial correlation coefficient from the measured radiation patterns of the parallel dipole array antenna shown in **Figure 7**(a), which is the basic multi-antenna configuration, obtained by this system. The radiation patterns of the two dipole antennas (800 MHz and 2 GHz) are measured for various values of antenna element spacing *d*. Although the spatial correlation coefficient depends on the power density function of arriving waves [6], we assumed that the power density function is uniform in the horizontal plane as shown in Fig. 7(a).

The spatial correlation coefficient derived from measured radiation pattern according to the element spacing is shown in Fig. 7(b) along with that derived from the calculated radiation patterns for comparison. From Fig. 7(b), we see that the agreement in the spatial correlation coefficient is high for both the 800 MHz and 2

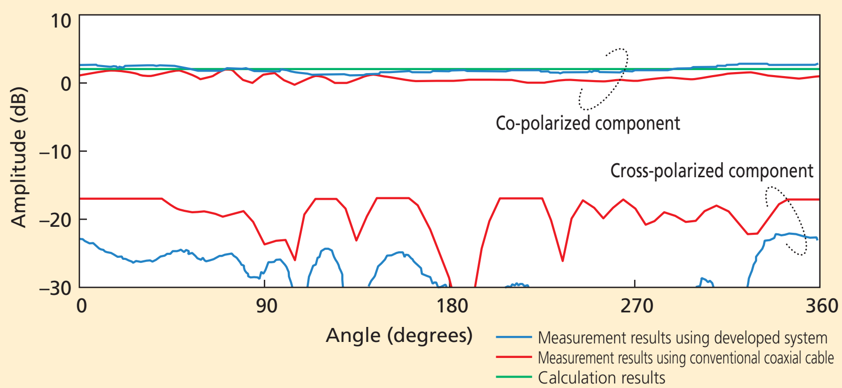


Figure 6 Radiation pattern of a standard dipole antenna (2-GHz band)

*9 **Far-field pattern integration methodology**: A method for obtaining the radiation efficiency of an antenna by comparing the total radiated power of the antenna derived from the integration of the far-field patterns to the total power input to the antenna.

*10 **Cross-polarized component**: Of the two polarizations, the polarization component that is orthogonal to the co-polarized component.

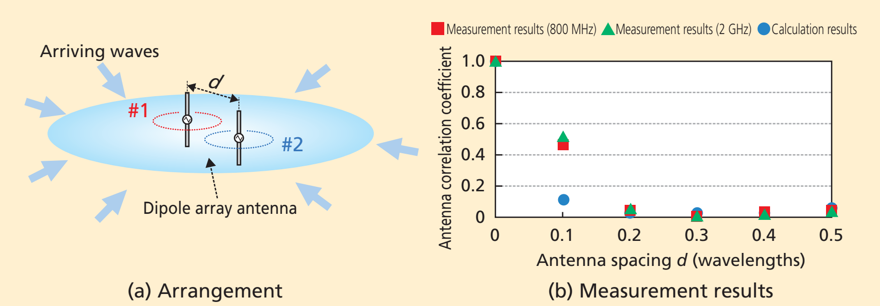


Figure 7 Spatial correlation coefficient for two dipole array antenna

GHz measurements, with a very low error of 0.1 or less, and highly accurate measurement with no effect from the nearby positioner device and feeder cable is possible even for the simultaneous multi-antenna measurements. In comparison with the numerical calculations, too, there is very good agreement in the range of element spacing of 0.2 wavelengths or higher. There is some error for the element spacing of 0.1 wavelengths, but the reason for that error is believed to be that the structure of the dipole antenna used in the numerical calculations is not completely consistent with that used in the actual measurements. Nevertheless, a detailed consideration of this result remains as an issue for future study. The above results confirm that this measurement system can be used to evaluate the spatial correlation coefficient of a multi-antenna for mobile terminal with sufficient measurement accuracy.

4.3 Reduction of Overall Radio Performance Measurement Time

To verify reduction of measurement time in measuring the overall mobile terminal radio performance using this system, we compared the TRP measurement time with that of the conventional method. This measurement system differs from the conventional configuration in the rotation method used by the positioner. As described in item 3) of Section 3.2, while the conventional configuration uses one-axis rotation in which measurements are taken while scanning in the azimuth direction with the fixed mobile terminal under test at one roll angle, this measurement system uses two-direction simultaneous rotation in which the mobile terminal under test is rotated in the roll and azimuth directions at the same time. The comparison of TRP measurement times for the different rotation methods are shown in **Figure 8**. The conventional one-axis rotation method requires only 30 seconds to complete one azimuth direction rotation at the rotation speed of 2 rpm, but the positioner must then be returned to the initial position for the next rotation, so the total time is approximately 40 seconds. The stepping rotation to the next angle also requires a few seconds. This series of measurements is performed 12 times, at 15° intervals from 0 to 165° in the roll-axis direction. Furthermore each scan must be done twice, once each for the vertical and horizontal polarization of the measurement antenna, so a total of approximately 17 minutes is required. In the two-axis simultaneous rotation method, on the other hand, the roll direction rotation speed is set to approximately 5 rpm and the azimuth direction rotation speed is set to approximately 0.2 rpm for azimuth and roll direction grid intervals of 15°, considering the updating interval for the Received Signal Code Power (RSCP)[*11] of the downlink common pilot channel, which is the received power of the mobile terminal needed for simplified measurement of the TIS (a criterion of receiver performance). As a result, the total measurement time for both polarizations is reduced to approximately 5 min-

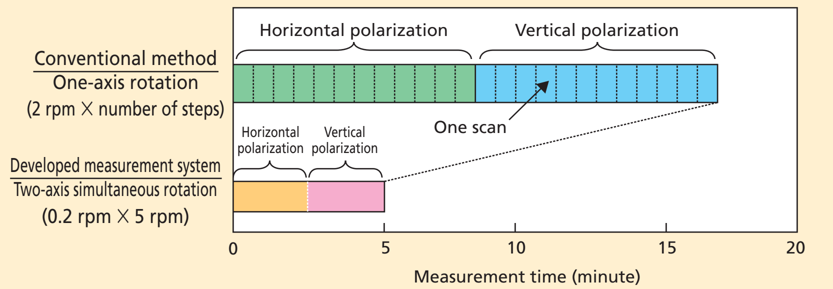


Figure 8 Comparison of TRP measurement time for different positioner rotation methods

*11 **RSCP**: A value that represents the received signal code power of the mobile terminal.

utes. Accordingly, this measurement system can reduce the TRP measurement time to 1/3 or less that of the conventional method. Here, the positioner rotation speed in the roll direction is set to a maximum of 5 rpm with the assumption of simultaneous measurement of the RSCP and the mobile terminal transmitting power, which is needed for the TRP measurement. If only the TRP is measured, however, the RSCP is not needed and the rotation speed can be set to above 5 rpm to further shorten the measurement time. As shown in **Figure 9**, the difference in the rotation method generates an error in the measurement grid interval, and the grid deformation in the case of the two-axis simultaneous rotation method affects the measurement accuracy. Nevertheless, the error relative to the TPR obtained by the conventional method is less than 0.1 dB, so we can conclude that this measurement system achieves both higher speed and higher accuracy in the evaluation of overall mobile terminal radio performance.

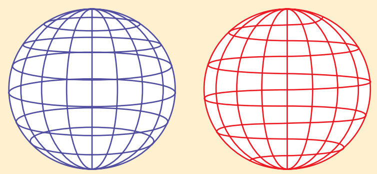


Figure 9 Comparison of measurement grid interval for different positioner rotation methods

5. Conclusion

With the purposes of increasing the speed and accuracy of mobile terminal antenna performance evaluation, we developed a mobile terminal antenna measurement system that can evaluate both antenna performance and the overall radio performance of the mobile terminal in a common measurement environment. The results of verification with a standard dipole antenna show that this measurement system can achieve highly accurate measurement of within an error of ±0.1 dB for antenna gain and efficiency and within an error of 0.1 for the spatial correlation coefficient of a multi-antenna configuration. In addition, by improving the rotation method of the positioning device in the three-dimensional measurements made for evaluating overall mobile terminal radio performance, we reduced the measurement time to 1/3 or less that of the conventional method.

In future work, we plan to apply this measurement system to further increase the performance of the FOMA terminal antenna and investigate the fundamental characteristics of antennas for MIMO transmission.

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