Mobile Terminal Antenna | OTA Performance | OTA Measurements

Evaluation of OTA Performance for Mobile Terminal Antennas Reflecting Practical Usage and Improvement of Measurement Efficiency

With the aim of developing a method for evaluating the OTA performance of FOMA terminal antennas while reflecting the characteristics in practical usage by users, NTT DOCOMO has introduced a measurement method for evaluating OTA performance in a speech mode, data-communications mode and standby mode that takes both the antenna section and RF transceiver section into account. This method has enabled us to improve effective radiated power and effective radiated sensitivity and to develop FOMA terminals with a high overall radio performance. We have also introduced a measurement system using a non-anechoic chamber that shortens the measurement time of OTA performance to about 1/6 that of the conventional method.

Communication Device Development Department

Yoshiki Okano
Daisuke Kurita
Shin Nakamatsu
Takashi Okada

1. Introduction

Together with propagation loss and interference margin, the performance of terminal-mounted antennas is an important component of link budget in a mobile communications system. The performance of a mobile terminal antenna is generally evaluated by measuring its radiation pattern in an anechoic chamber[*1]. This has traditionally been performed by a passive measurement method that feeds the antenna from an external signal source via a coaxial cable. However, due to the fact that passive measurement requires that a feeder cable be drawn to the Device Under Test (DUT), spurious emission caused by leaked current around this feeder cable can significantly degrade measurement accuracy. To overcome this problem and to enable antenna characteristics to be evaluated in the product's final state, the active measurement method has come to be used in recent years. This method measures the antenna radiation pattern with high accuracy by using the terminal's own Radio Frequency (RF) transceiver section as an internal signal source and by establishing a radio link with a base station emulator. It also enables evaluation of overall radio performance for a mobile terminal antenna reflecting, for example, the impedance matching state[*2] between the antenna and RF transceiver sections.

At first, this active measurement method was used to evaluate relative gain with respect to a standard antenna, but this limited the target of evaluation to the antenna unit. In response to this

*1 **Anechoic chamber**: An experimental facility that blocks the penetration of external radio waves and suppresses wave reflection by covering the six interior walls of the chamber with radio-wave absorbers.

*2 **Impedance matching state**: A state in which electrical characteristics on the input side of a transmission line match those on the output side.

issue, CTIA-The Wireless Association, has proposed an evaluation method that expands upon the active measurement method. This method measures a terminal's effective radiated power and effective radiated sensitivity in three dimensions and evaluates overall radio performance of the mobile terminal including the antenna [1]. Evaluation of terminal-antenna performance based on effective radiated power and effective radiated sensitivity is generally referred to as Over-The-Air (OTA) measurement. The 3rd Generation Partnership Project (3GPP) has also adopted an OTA measurement method similar to that of CTIA based on the results of studies conducted by European Cooperation in Science and Technology (COST) [2] [3]. On receiving those results, 3GPP established performance specifications using as figures of merit Total Radiated Power (TRP) for transmit performance and Total Radiated Sensitivity (TRS) for receive performance [4].

As described above, conventional antenna performance evaluation targets only the antenna unit using a standard antenna as a reference. A major difference between this approach and OTA performance evaluation based on TRP and TRS is that the latter evaluates overall radio performance that combines the performances of the antenna and RF transceiver sections in the DUT. Here, TRP and TRS include all radio sections that make up a terminal as targets of evaluation and therefore represent absolute performance evaluation based on the terminal's effective radiated power and effective radiated sensitivity via the antenna. Hence, TRP and TRS can be called performance evaluation metrics that faithfully reflect radio characteristics under conditions that reflect the practical usage of mobile terminals.

For the above reasons, we introduced a method for evaluating the overall radio performance of a terminal antenna (OTA performance evaluation method) for FOMA terminals (**Figure 1**). However, compared to the conventional measurement method, this performance evaluation method was found to require a huge amount of measurement time, and to implement it, studies had to be made on ways of making measurements more efficient.

In this article, we describe our newly introduced OTA measurement system using a reverberation chamber for measuring the overall radio performance of FOMA terminal antennas and explain how it makes the measurement process vastly more efficient through a reduction effect in the time required for measurements.

2. OTA Performance Evaluation Method

2.1 OTA Performance Requirements and Figures of Merit

The basic approach to OTA performance requirements is shown in **Figure 2**. To establish these requirements, the performance of both the antenna section and RF transceiver section must be taken into account. For the antenna section, required antenna performance that must be satisfied by the antenna

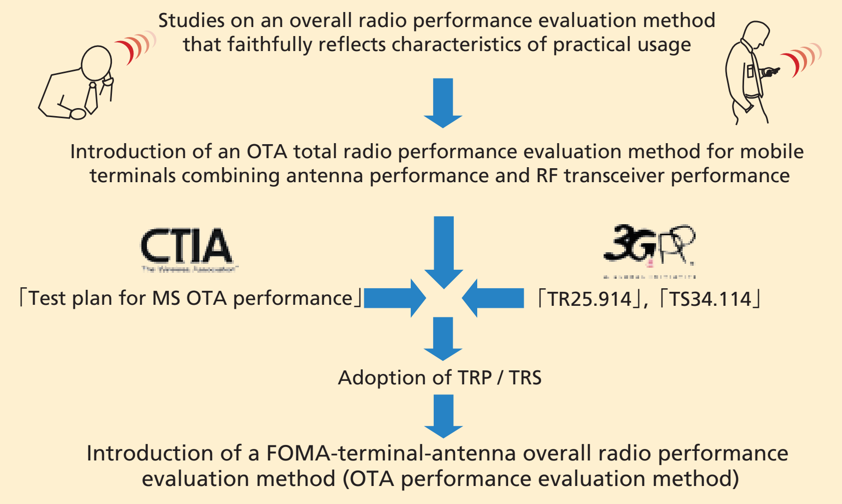


Figure 1 Introduction of an OTA performance evaluation method: background and objective

unit is established using Total Radiated Power Gain (TRPG) as shown in equation (1).

$$TRPG=\frac{1}{4\pi}\int_0^{2\pi}\int_0^{\pi}(G_\theta+G_\phi)\sin\theta\, d\theta\, d\phi \quad (1)$$

Here, θ and ϕ constitute a coordinate system in which the former denotes the vertical angle and the latter the horizontal angle of the DUT, and G_θ and G_ϕ denote the vertical and horizontal polarization components, respectively, of the antenna gain pattern. In the equation, TRPG is defined as the power radiated over all directions and polarizations divided by the total power accepted by the antenna at the input port, which is identical with the classical definition of radiation efficiency.

For the RF transceiver section, reference is made to 3GPP specifications [5] that stipulate conducted performance to be guaranteed under the full temperature range indicated, and the typical values specified there are set here as required RF transceiver section performance. Furthermore, the maximum transmit power that indicates transmit performance takes into account the allowed deviation described in Section 6.2 “Transmit power” of the 3GPP TS25.101 technical specification. As for radiated sensitivity that indicates receive performance, the power density per chip per channel (DPCH_Ec) indicated in Section 7.3 “Reference sensitivity level” of the same technical specification is converted to the in-band power density of the antenna’s connector port (REFÎor) for a Bit-Error-Rate (BER) threshold of 0.1%, and REFÎor is additionally converted to the value for a BER threshold of 1% under the same conditions as those when making TRS measurements. This derives required RF transceiver performance.

We therefore combine required antenna performance and required RF transceiver performance established in the above way and establish OTA performance requirements using the TRP and TRS performance evaluation metrics shown in equations (2) and (3).

$$TRP=\frac{1}{4\pi}\oint\left(P_{tx}G_\theta(\Omega;f)+P_{tx}G_\phi(\Omega;f)\right)d\Omega \quad (2)$$

$$TRS=\frac{4\pi}{\oint\left[\frac{1}{EIS_\theta(\Omega;f)}+\frac{1}{EIS_\phi(\Omega;f)}\right]d\Omega} \quad (3)$$

Here, G_θ and G_ϕ denote the vertical and horizontal polarization compo-

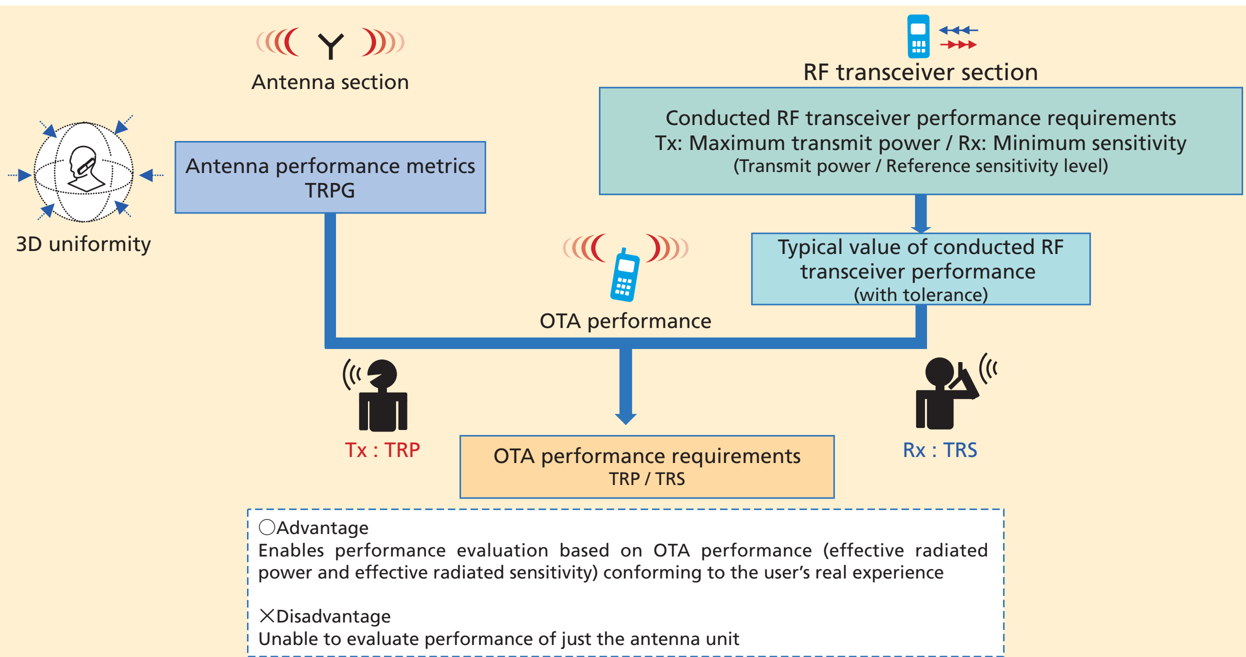


Figure 2 Approach to OTA performance requirements

nents, respectively, of the antenna gain pattern at frequency f and Ω denotes the solid angle[*3]. In addition, P_{tx} is the transmit power of the DUT so that $P_{tx}\, G_{\theta}$ and $P_{tx}\, G_{\phi}$ denote effective radiated power known as Equivalent Isotropically Radiated Power (EIRP). Effective Isotropic Sensitivity (EIS) is the antenna output terminal power for the required sensitivity threshold with respect to each polarization component.

Although OTA measurements as described above cannot evaluate the performance of the terminal's antenna unit itself, it can evaluate the mobile-terminal's overall radio performance combining the antenna section and RF transceiver section. This makes it possible, for example, to adjust impedance matching between the antenna and RF transceiver sections in their implemented state and to optimize the transmission line configuration between the antenna and RF transceiver sections. Adjustment of a terminal's radio characteristics based on the results of OTA measurements can contribute greatly to improving effective radiated power and effective radiated sensitivity of the mobile terminal.

2.2 OTA Measurement System

An ordinary OTA measurement system in an anechoic chamber is shown in **Figure 3**. Since an actual terminal is used as the DUT in OTA measurements, a base station emulator is prepared and a radio link is established with the DUT via a measurement antenna installed on an antenna tower in the anechoic chamber. The measurement antenna has a polarization switching mechanism so that measurements can be taken for both the vertical and horizontal polarization components. Furthermore, to evaluate performance in three dimensions, positioning equipment is installed to rotate the DUT about two axis, namely, an azimuth axis[*4] and a roll axis[*5]. The effective radiated power and effective radiated sensitivity are measured at each DUT setup angle spanning all directions to determine TRP and TRS. These series of measurements are all remotely controlled by measurement software installed in the control PC thereby achieving automatic measurement of TRP/TRS by an OTA measurement system.

It should be pointed out here that TRP/TRS measurements using an OTA measurement system as described above include much uncertainty depending on the measurement accuracy of each piece of equipment making up the measurement system and on the measurement procedure as well, and that some of this uncertainty cannot easily be resolved. For this reason, 3GPP has defined measurement-error tolerances with respect to TRP and TRS [4].

2.3 Consideration of Practical Usage Modes for Mobile Terminals

At present, 3GPP targets only the "speech mode" as mobile terminal usage in the evaluation of a mobile terminal's antenna performance and specifies recommended performance and minimum requirements (**Table 1**) [4]. For example, the recommended perfor-

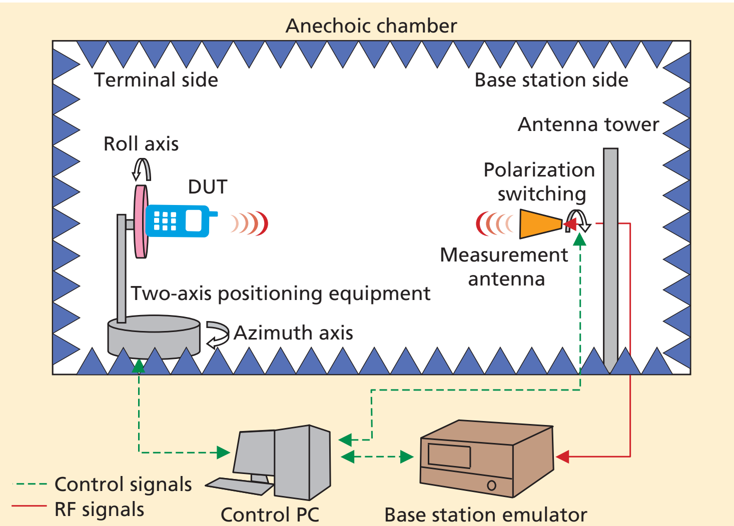


Figure 3 Ordinary OTA measurement system in an anechoic chamber

*3 **Solid angle**: Area of a spherical surface cut away by a cone whose vertex is the center of the sphere.

*4 **Azimuth axis**: An axis of rotation oriented in a vertical direction in two-axis positioning equipment.

*5 **Roll axis**: An axis of rotation oriented in a horizontal direction in two-axis positioning equipment.

mance and minimum requirements for TRP/TRS in Band I (2 GHz) are +18/–104 dBm and +15/–101 dBm, respectively. However, to evaluate performance taking into account the ways in which users actually use mobile terminals, due consideration must also be given to "data-communications mode," which is a type of packet communications that has come to be used frequently in recent years, and "standby mode". Thus, in the OTA performance evaluation of terminals, it is important that the three usage modes of speech, data communications, and standby be considered (**Photo 1**).

In the speech mode, the effects of the human head in close proximity to the DUT must be taken into account. For this reason, measurements for this mode are performed by placing the DUT at a "cheek position" specified by the Institute of Electrical and Electronics Engineers (IEEE) [6] and the European Committee for Electrotechnical Standardization (CENELEC) [7] with respect to a phantom human head as specified by the Specific Anthropomorphic Mannequin (SAM) standard*6. Under this placement condition, the surface of the DUT is in contact with the cheek of the head phantom.

Next, in the data-communications mode, the effects of the user's hand holding the mobile terminal must be taken into account. Measurements are performed here in a mode in which the DUT is held by a phantom human hand. At present, the structure, materials, and electrical constants of this hand phantom and the DUT placement position are being discussed at CTIA and plans are being made to standardize the hand phantom in accordance with terminal shapes.

Finally, in the standby mode, measurements are performed in "free space" in which no lossy obstacle such as a human head or hand is placed near the DUT. In the case of a clamshell-shaped terminal, measurements are taken with the terminal in a mechanically closed mode.

3. Improvement of Measurement Efficiency

In the ordinary OTA measurement system described in Section 2.2, TRP and TRS measurements are performed repeatedly at fixed intervals of 15 and 30 degrees or less, respectively, covering all directions in three dimensions. A full set of measurements therefore requires a huge amount of time. This is particularly true in measuring radiated sensitivity to derive TRS since BER must be repeatedly measured at the DUT while gradually lowering the output power of the base station emulator. Here, TRS measurement time per channel generally takes more than one hour. Measurements must also be performed for the low (L), medium (M), and high (H) channels of each frequency band and, with regard to terminal placement conditions, for a DUT placed at both the right and left sides of a head phantom. A huge amount of time is therefore needed to complete all measurement items.

This, with the aim of making OTA measurements more efficient, we intro-

Table 1 OTA performance requirements at 3GPP

Band	Recommended performance (dBm)		Minimum requirement (dBm)	
	TRP	TRS	TRP	TRS
I (2 GHz)	+18	−104	+15	−101
VI (800 MHz)	+14.5	−101	+11	−96
IX (1.7 GHz)	+18	−103	+15	−100

(a) speech mode (b) data-communications mode (c) standby mode (mechanically closed mode)

Photo 1 Usage modes of mobile terminals

*6 **SAM standard**: A standard of the International Electrotechnical Commission (IEC) specifying a human head model.

duced a measurement system using a non-anechoic chamber called a "reverberation chamber" [8] as described below.

1) Configuration of OTA Measurement System Using a Reverberation Chamber

The configuration of an OTA measurement system using a reverberation chamber is shown in **Figuer 4**. As described in Chapter 1, the evaluation of antenna performance is generally carried out by measuring the antenna's radiation pattern targeting only direct waves in an anechoic chamber that suppresses reflected waves by radio-wave absorbers. In contrast, a reverberation chamber is a metal cavity equipped with multiple stirrers, a rotating platform, and multiple wall antennas and measurements are performed while "stirring" reflected waves.

In this measurement system, signals from the base station emulator arrive at the DUT via the wall antennas in the reverberation chamber. At this time, the system activates the stirrers and the rotating platform on which the DUT rests and performs switching among the wall antennas so as to create a Rayleigh fading[*7] environment having a statistically three-dimensional uniform distribution in the vicinity of the DUT. Thus, during the time that these stirrers and other components are activated, a steady three-dimensional uniform Rayleigh fading environment is generated, and in this state, a radio link is established between the DUT and base station emulator enabling the radiated power and radiated sensitivity of the DUT to be measured in three dimensions.

2) Comparison of TRP/TRS Derivation Methods

The differences in TRP/TRS derivation between an anechoic chamber and reverberation chamber are summarized in **Figuer 5**. In the case of an anechoic chamber, the system repeatedly measures radiation pattern in all directions to obtain a three-dimensional radiation pattern for all space and integrates this pattern to derive TRP and TRS. However, when using a reverberation chamber, the system obtains multiple measurement samples for transmit power or radiated sensitivity. Although

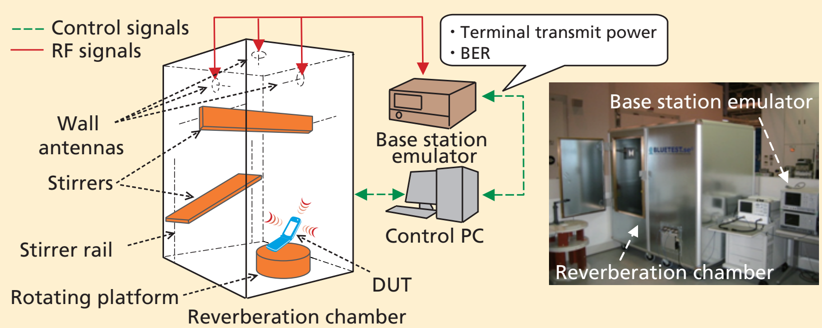


Figure 4 Configuration of reverberation-chamber OTA measurement system

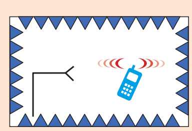
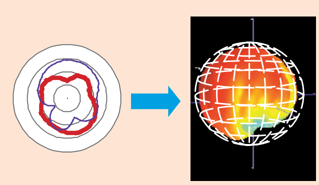
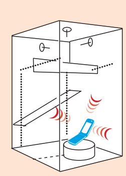
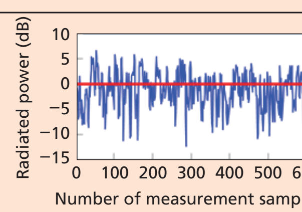
Measurement environment	Measured data	Data processing method
 Anechoic chamber		Integration
 Reverberation chamber	 Transmit power / Radiated sensitivity	Averaging

Figure 5 Differences in TRP/TRS derivation methods

*7 **Rayleigh fading**: Fading characteristics typical of a non-line-of-sight environment in mobile communications.

these measurement samples (instantaneous values) fluctuate in a range exceeding 20 dB, TRP and TRS can be statistically obtained by averaging of the measured samples.

As a measurement method using reflected waves, the reverberation-chamber method cannot obtain the radiation pattern of the antenna targeted for measurement. It can, however, generate a uniform three-dimensional Rayleigh fading environment with high reproducibility making it ideal for TRP/TRS measurements, which assume a three-dimensional environment.

3) Reduction of Measurement Time

Figuer 6 compares OTA measurement time between the conventional measurement method using an anechoic chamber and the newly introduced measurement method using a reverberation chamber. Measurement time for the anechoic chamber was obtained by the two-axis-positioner measurement system shown in Fig. 3 and that for the reverberation chamber by the measurement system shown in Fig. 4. First, for TRP, which indicates transmit performance, the results of Fig. 6 show that about six minutes per channel are needed for measurements when using an anechoic chamber but only about one minute when using a reverberation chamber. Measurement time can therefore be reduced to about 1/6 that of the conventional method. Next, for TRS, which indicates receive performance, it was explained in Section 2.2 that a huge amount of time is required for those measurements—about ten times that needed for TRP. However, when using a reverberation chamber, measurement time is only about 1/6 that of an anechoic chamber resulting in a significant reduction in measurement time. In addition, TRP/TRS measurement results obtained by using a reverberation chamber show good agreement with those of an anechoic chamber, which demonstrates that measurement efficiency can be improved while maintaining measurement accuracy.

4. OTA Performance Measurement Results for FOMA Terminals

Figuer 7 shows the results of OTA performance measurements for five models of FOMA terminals in speech mode in the 2 GHz band when using a

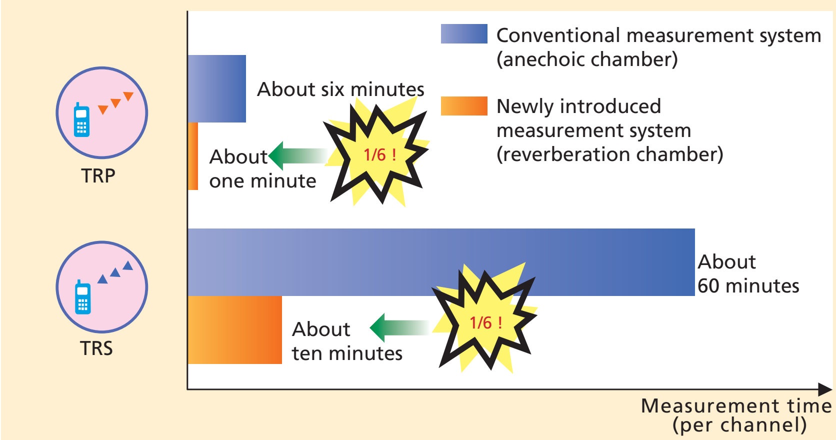


Figure 6 Measurement-time reduction effect

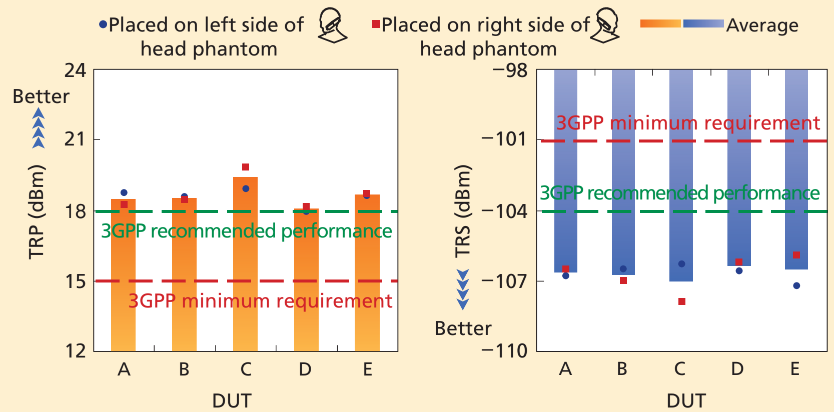


Figure 7 Results of OTA performance measurements for FOMA terminals (2 GHz band)

reverberation chamber. First, for TRP, it can be seen that all DUTs exhibit performance that exceeds both the 3GPP minimum requirement and recommended performance. It can also be shown that these terminals have a high level of performance with regard to TRS exceeding both the 3GPP minimum requirement and recommended performance. As for FOMA terminals that are coming to support multiband operation [9] while simultaneously becoming smaller, low-profiled and multifunctional, a number of technical issues must be overcome with regard to the mobile terminal antenna in order to satisfy the 3GPP minimum requirement and recommended performance specified for each frequency band. In response to these issues, measures are being implemented to prevent interference with components mounted near the antenna and to utilize the current widely spread over the mobile terminal chassis. With measures such as these, NTT DOCOMO is developing FOMA terminals that feature high OTA performance and stable use over a wide area.

5. Enhancement of Reverberation-chamber Measurement System

5.1 Evaluation of Intra-terminal Interference Effects

While TRP and TRS indicate basic radio performance in a comprehensive manner, the effects of intra-terminal interference must also be considered to further reflect the user's real experience. This is because interference generated in the mobile terminal itself may degrade radiated sensitivity even if the antenna and RF transceiver sections have sufficient performance with regard to TRS, that is, receive performance. Interference that contributes to degraded radiated sensitivity may originate in a liquid-crystal display, camera module, processor, digital interface, or other device. Such types of interference occur in the terminal's reception band and penetrate the receiver via the antenna or an internal transmission line to degrade radiated sensitivity. Various countermeasures to intra-terminal interference that degrades radiated sensitivity can be considered such as the use of shields to block the interference source and the optimization of terminal structure, component arrangement, and position of the antenna feed point. The overall-radio-performance evaluation method introduced here can quantitatively evaluate the effects of applying such interference countermeasures, and at the same time, its use of a reverberation chamber can make the measurement process for evaluating the effects of intra-terminal interference much more efficient.

5.2 Multi-antenna Measurement

The introduction of Multiple Input Multiple Output (MIMO) transmission technology is being studied with the objective of improving the peak data rate in the Long Term Evolution (LTE) system [10] that aims to achieve both wide-area capabilities and high-speed data transmission at a high level. This will require that mobile terminals also mount a multiple-antenna system consisting of multiple antenna elements. Here, however, the conventional radiation-pattern measurement method using an anechoic chamber is incapable of measuring multi-antenna performance. In particular, there is a need for a measurement environment that can reproduce the angular spread of arriving waves in order to evaluate the spatial correlation between antennas. A reverberation chamber that can make OTA measurements more efficient can also reproduce the angular spread of arriving waves and can therefore be applied to evaluating multi-antenna performance as well [11].

6. Conclusion

With the aim of establishing a FOMA-terminal antenna performance evaluation method that faithfully reflects the characteristics of practical usage by FOMA users, NTT DOCOMO has introduced an OTA performance evaluation method that evaluates overall radio performance in a speech mode, data-communications mode, and standby mode taking into account both the antenna section and RF transceiver section of the mobile terminal. With this method, we have successfully developed FOMA terminals having high overall radio performance. We have also introduced a measurement system based on a non-anechoic chamber called a "reverberation chamber" that shortens OTA measurement time to about 1/6 that of the conventional method while maintaining measurement accuracy. In future research, we plan to study the possibilities of applying this reverberation chamber to the evaluation of multi-antenna performance.

References

[1] CTIA Certification: "Test plan for mobile station over the air performance Rev.2.2."

[2] 3GPP TR 25.914 V.1.0.0: "Measurements of radio performances for UMTS terminals in speech Mode."

[3] 3GPP TS 34.114 V.7.0.0: "User Equipment (UE) / Mobile Station (MS) Over The Air (OTA) antenna performance; Conformance testing (Release 7)."

[4] 3GPP TS 25.144 V.7.0.0: "User Equipment (UE) and Mobile Station (MS) over the air performance requirements."

[5] 3GPP TS 25.101 V.8.4.0: "User Equipment (UE) radio transmission and reception (FDD)."

[6] IEEE standard P1528: "Recommended Practice for Determining the Peak Spatial-Average Specific Absorption Rate (SAR) in the Human Head from Wireless Communications Devices: Experimental Techniques," Apr. 2003.

[7] CENELEC Standard ENS 50361: "Basic Standard for the measurement of Specific Absorption Rate related to human exposure to electromagnetic fields from mobile phones (300 MHz-3 GHz)," CENELEC, p. 51, Jul. 2001.

[8] P. S. Kildal: "Overview of 6 Years R&D on Characterizing Wireless Devices in Rayleigh Fading Using Reverberation Chambers," iWAT2007, 2007.

[9] M. Koiwa et. al: "Multiband Mobile Terminals," NTT DoCoMo Technical Journal, Vol. 8, No. 2, pp. 31-38, Sep. 2006.

[10] 3GPP Release 8.

[11] D. Kurita, Y. Okano, S. Nakamatsu and T. Okada: "Study on multi-antenna measurement system using reverberation chamber," IEICE Technical Report, AP2008-187, Jan. 2009 (in Japanese).