Radio frequency safety | Mobile base station | Antenna

Technology Reports

Evaluating RF Field Intensity in Mobile Base Station Environments

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Reference levels for the intensity of radio frequency (RF) fields emitted by mobile base stations in areas where people normally enter are restricted by the Radio regulation, and compliance with these reference levels is checked using evaluation methods stipulated in related bulletins. However, measuring RF fields from mobile base stations accurately requires time and specialized technology. Thus, there is a need to automate the measurement process, to reduce the time required, and simplify operation of the equipment, making measurements more efficient and ensuring reproducibility of measurements.

In this report, we describe the Radio regulations regarding intensity of RF fields emitted by mobile base stations, methods for evaluating them as specified in related bulletins, and the configuration of equipment developed to measure and visualize it.

1. Introduction

Mobile base stations (hereinafter referred to as "base stations") are relay points connecting smartphones and mobile phones with the network. They are composed of radio transmitter and receiver equipment and antenna systems. Recently, NTT DOCOMO has been providing communications services using base stations that combine the LTE and W-CDMA formats. They are also utilizing multiple frequency bands in order to expand the system capacity. There are many types of base station antenna, from relatively large devices that are installed on the rooftops of office and apartment buildings to cover large outdoor communication areas, to relatively small devices installed in more localized areas with high traffic, such as underground shopping malls and inside buildings. The intensity of RF fields emitted from these various base stations, which are optimized to obtain a regulated level of communications quality, depends on parameters such as transmission power, antenna gain*1 and antenna directivity characteristics. In this report, we will refer to this environment, with RF signals from multiple base stations, as the mobile base station environment.

To protect human health, Radio regulations in Japan stipulate RF intensity reference values*2 and impose a duty to ensure that the intensity does not exceed these reference levels in areas frequented by general public [1]. These reference levels are equivalent to those in guide-

*1 **Gain**: One of the radiation characteristics of an antenna. An indicator of how many times larger the radiation strength in the antenna's direction of peak radiation is relative to a standard antenna.

lines published by the International Commission on Non-Ionizing Radiation Protection (ICNIRP)*3 [2]. Methods to check compliance with these RF field intensity reference levels are also stipulated in bulletins related to the Radio regulations [3].

Technical standards from the Association of Radio Industries and Businesses (ARIB) and standards from the International Electrotechnical Commission (IEC) give specific methods for evaluating RF field intensity from base stations for checking compliance, and for evaluating uncertainty in the measurements [4] [5]. Mobile radio operators design and operate their base stations based on these and other regulations. Note that when checking compliance, the total RF field intensity must be evaluated, not limited to the nearest base station but including signals from other nearby base stations and other systems and radio signal sources [1]. Because of this, making accurate measurements of RF field intensity in mobile base station environments requires much time and specialized technology. To measure RF field intensity efficiently and reproducibly when installing and operating base stations, measurements must be automated, reducing the time required and simplifying operation of the equipment.

As such, NTT DOCOMO has developed equipment (hereinafter referred to as "the equipment") to measure RF field intensity in mobile base station environments.

In this report, we describe a method for evaluating RF field intensity in mobile base station environments, the configuration of the equipment, and a method to evaluate uncertainty in the measurements. Note that we are assuming the 3GPP Rel. 8 standard for LTE.

2. Evaluating RF Field Intensity

2.1 Checking Compliance with Reference Levels

In mobile base station environments like that shown in **Figure 1**, the total RF intensity from the nearest and other nearby base stations, as well as from other systems that are RF sources, must be evaluated [1]. This total value is defined as the Total Normalized Electrical Field Strength, e^2_{Total}, and an e^2_{Total} value less than 1 confirms compliance with reference levels. e^2_{Total} is calculated by:

$$e^2_{\text{Total}} = \sum_{i=1}^{N} \frac{E^2(f_i)}{E^2_{\text{R}}(f_i)} \quad (1)$$

where E is the electrical field strength at frequency f_i, E_{R} is the reference level of electrical field strength indicated in Radio regulations, and N is the number of sources of different frequencies. Dividing the normalized electrical field strength into that from the base stations and that from other systems, e^2_{Total} can be expressed as:

$$e^2_{\text{Total}} = e^2_{\text{MBS}} + e^2_{\text{Other}} \quad (2)$$

Here, e^2_{MBS} is the normalized electrical field strength of RF field emitted from

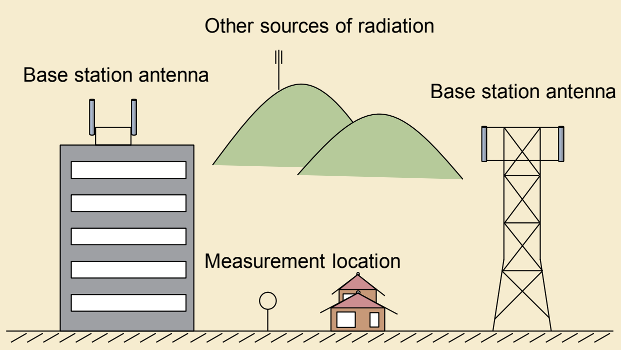

Figure 1 Example of the mobile base station environment

*2 **RF intensity reference values:** RF intensity values specified in Radio Law Enforcement Regulation No. 21-3 and Annex Table No. 2-3-2. Reference values are defined for electrical field strength, magnetic field strength, and electrical power density, and they are dependent on frequency. This paper mainly deals with methods for calculating electrical field strength.

*3 **ICNIRP:** An affiliate of the World Health Organization (WHO).

the nearest and other nearby base stations, and e^2_{Other} is that emitted from other systems that are RF sources.

2.2 RF Field Intensity Measurement System

Options and conditions for systems that measure RF field intensity are regulated, and to take measurements at selected frequencies, a system composed of an antenna that detects the electrical field (hereinafter referred to as "electrical-field sensor") and a spectrum analyzer is used [3]-[5]. One issue when taking measurements is that the electrical-field sensor must be oriented in the direction and plane of polarization*4 that yields the maximum reading on the device, but signals reach the sensor from multiple directions, so it is best to use a sensor that has isotropic antenna directivity*5.

Note also, that the effect of other sources on the observed RF field intensity is extremely small near the base station antenna, compared to far from the antenna. Also, the RF field intensity directly below the antenna varies considerably with height, so measurements must be taken using a compact electrical-field sensor with high spatial resolution [6]. In this report, we consider public environments where people come and go, outside of base stations. Measurements are taken far from the antenna, so high sensitivity in the measuring instruments is more important than high spatial resolution.

2.3 Measurement of Fluctuating RF Field Intensity

Generally, the RF field intensity at the point of measurement fluctuates over time, with fluctuations in propagation losses between the source and observation point and in the source transmission power. From the perspective of checking compliance, RF intensity must be evaluated conservatively to ensure, at least, that it is not evaluated too low. We describe methods for evaluating the various fluctuation components below.

1) Evaluating the component due to transmission loss fluctuation

RF field intensity reference levels must be averaged over six minutes according to regulations [1]. The component due to transmission loss fluctuation can be evaluated by averaging the measured values. Alternately, by considering the measurement uncertainty related to propagation loss fluctuation as described below, RF field intensity can be evaluated conservatively. Here, to achieve both a conservative evaluation of RF field intensity and shorter measurement time, we use the latter method. We get the instantaneous RF field intensity at the observation point from the frequency spectrum observed using the spectrum analyzer. Equation (2) can be used to evaluate compliance based on the measured values [7].

2) Evaluating fluctuation due to changes in source transmission power

It is very difficult to obtain the RF field intensity for the case when all relevant base stations transmit at their maximum power, even when taking measurements over several days for example, considering that for base stations in particular, transmission power fluctuates based on fluctuations in communications traffic. Thus, a method was needed to obtain RF field intensity values equivalent to the maximum traffic values for LTE and W-CDMA base stations, even as traffic fluctuates, and achieving both a conservative evaluation of RF field intensity and short measurement time. We used a method in which we measure the RF field intensity for a channel transmitting at a fixed transmission power, even while the traffic is fluctuating, and extrapolate to get a RF field intensity value for the maximum traffic conditions by multiply by a factor based on the ratio of the maximum transmission power of the base station to the transmission power of that channel.

To calculate an RF field intensity value for maximum traffic on a given carrier for LTE and W-CDMA base stations, we use the Cell-specific Reference Signal (CRS)*6 for the LTE system, and the Common PIlot CHannel (CPICH) for the W-CDMA system respectively, which are both down-link transmitted signals. The each transmission power for CRS and CPICH is fixed, and the maximum transmission power per carrier is in the base station specifications. Thus, the RF field intensity for a given carrier at maximum transmission power can be obtained by multiplying the CRS or

*4 **Plane of polarization:** The plane determined by the propagation direction of an electromagnetic wave and the direction of the electric field.

*5 **Antenna directivity:** One of the radiation characteristics of an antenna. The directional characteristics of the radiated or received strength of the antenna.

*6 **CRS:** A reference signal specific to each cell for measuring received quality in the downlink.

CPICH power by a ratio determined by the base station specifications. Taking the electrical field strength for these channels to be E_{RS} and E_{CPICH}, the electrical field strength for each carrier with maximum traffic, E_{LTE} and E_{CDMA} respectively, can be calculated as follows:

$$E_{LTE} = \sqrt{\frac{N_{RS}}{F_B}} \cdot E_{RS} \quad (3)$$

$$E_{CDMA} = \sqrt{\beta} \cdot E_{CPICH} \quad (4)$$

Here N_{RS} is a factor representing the number of Resource Elements (RE)*7 of the carrier in the frequency direction, and F_B is a boosting factor*8. β is a factor representing the ratio of the maximum transmission power to the CPICH transmission power for the applicable carrier. To measure E_{RS} and E_{CPICH}, wireless channel decoders for LTE and W-CDMA are used [8].

By measuring E_{RS} and E_{CPICH} and using the results to calculate Equations (3) and (4) by elements such as sector, carrier, frequency band and communications operator, the total normalized electrical field strength shown in Equation (2) can be calculated, and the normalized electrical field strength can be analyzed for each element. An example of the elements comprising normalized electrical field strength is shown in **Figure 2**.

3. RF Field Intensity Measurement Equipment Configuration

The configuration of the equipment developed is described below.

The equipment is composed of an isotropic electrical field sensor, a switch, a spectrum analyzer, a wireless channel decoder, and a mobile PC, as shown in **Figure 3**. An external view of the equipment is shown in **Figure 4**. The isotropic electrical field sensor is attached to the main unit when taking measurements and removed to make transport easier. The main specifications of the equipment are shown in **Table 1**. RF field measurements in the range from 30 MHz to 3 GHz can be taken, so the main radio sources in ordinary environments are covered, including base stations and other radio sources such as part of the broadcast spectrum. In all of the frequency bands mentioned above, the electrical field strength can be measured to a sensitivity below 1 mV/m, or a normalized electrical field strength of less than 10^{-10}. However, when a relatively strong signal is detected, the sensitivity is automatically adjusted. To improve efficiency of RF field intensity measurements outdoors, the system is also able to operate continuously for three hours on its internal batteries.

The isotropic electrical field sensor

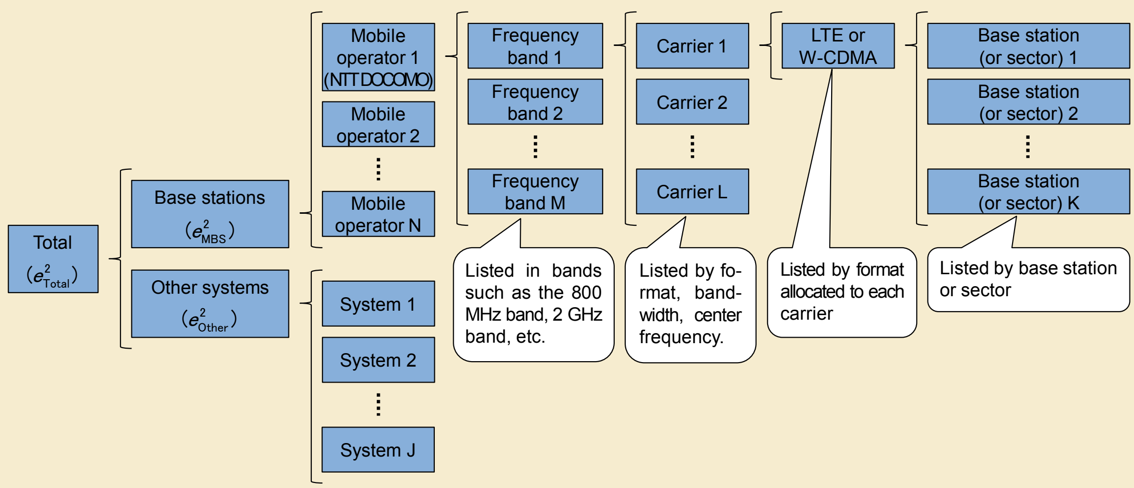

Figure 2 Example of the elements comprising normalized electrical field strength

*7 **RE:** A component of the downlink resource, composed of one subcarrier and one OFDM symbol.

*8 **Boosting factor:** A factor by which the CRS transmission power is increased while maintaining the transmission power for one OFDM symbol.

has three orthogonal antenna elements composed of wide-band sleeve dipoles, achieving high sensitivity over a wide bandwidth. The wide-band sleeve dipole is composed of an radiating element*9, a sleeve*10, and an FRP cover to protect them, as shown in **Figure 5**. The sleeve and radiating element structure has multiple conductors connected by inductors, and the conductor lengths are selected to be log-periodic in frequency. To suppress unbalanced currents in the coaxial feeder*11, circular ferrites*12 are introduced into the sleeve.

Defining the electrical field strengths observed on each of the antenna elements of the isotropic electric field sensor as E_x, E_y, and E_z, the electric field strength, E, at the observation point is calculated as follows:

$$E = \sqrt{E_x^2 + E_y^2 + E_z^2} \quad (5)$$

The normalized electrical field strength from sources besides base stations in Equation (2), e_{Other}^2, is calculated from the instantaneous electrical field strength measured using the spectrum analyzer. On the other hand, the normalized electric field strength from base stations, e_{MBS}^2, is calculated by measuring E_{RS} and E_{CPICH} in Equations (3) and (4) using a wireless channel decoder. The mobile PC performs the calculations in Equations (2) through (5), displays a graph of the e_{Other}^2 and e_{MBS}^2 frequency components on the same frequency axis, and displays evaluation results including the total normalized

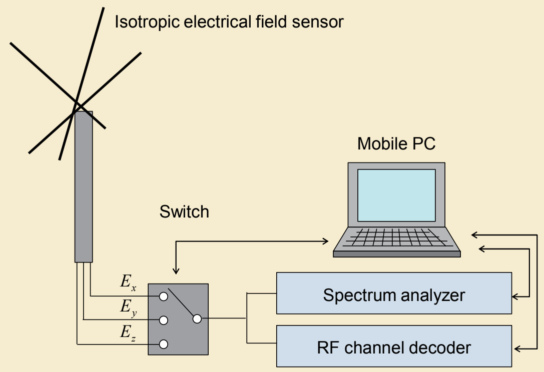

Figure 3 Basic configuration of RF field intensity measuring equipment

(a) For transport (b) While taking measurements

Figure 4 RF field intensity measuring equipment external view

Table 1 Main specifications of the RF field intensity measuring equipment developed

Frequency range	30 MHz to 3 GHz
Sensitivity	< 1 mV/m
Main analytical functions	Radio frequency spectrum
	LTE signal analysis
	W-CDMA signal analysis
Power	Over 3 h of operation on internal batteries
Weight	< 22 kg

*9 **Radiating element:** A metal component on which the high frequency electrical current flows and which dominates the gain and directivity characteristics of an antenna.

*10 **Sleeve:** A coaxial metal tube, of the same length as the coaxial cable radiating element comprising a sleeve dipole antenna, which is attached to the outside of the outer conductor.

*11 **Coaxial feeder:** a feeder line consisting of a coaxial cable.

*12 **Ferrite:** A magnetic material, used here to suppress common mode currents produced in the coaxial cable.

electrical field strength. An example of the mobile PC screen displaying the measurement results is shown in **Figure 6**.

Operation of the spectrum analyzer and other devices in this equipment is automated by a dedicated program, so that measurement operations can be done by simply pushing a start button. The equipment is able to measure RF field intensity, based on frequency spectrum measurements over the frequency range shown in Table 1, in approximately five minutes, and to measure RF field intensity equivalent to maximum traffic conditions, based on wireless channel decoder measurements, in approximately ten minutes. In these ways, the equipment reduces the time required and simplifies operation by automating the measurements, contributing to increasing efficiency and maintaining reproducibility of RF field intensity measurements in mobile base station environments.

4. Estimation of Uncertainty in Measured Values

Generally, values obtained through measurement always include uncertainty. IEC and the International Organization for Standardization (ISO) publish guides on uncertainty [5] [9], and we have evaluated the measurement uncertainty for

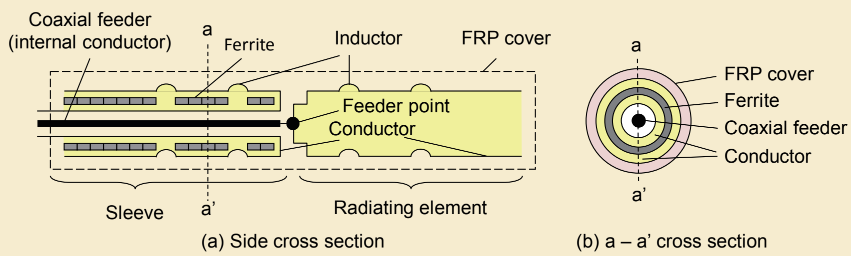

Figure 5　Structure of the wide-band sleeve dipole comprising the isotropic electrical field sensor

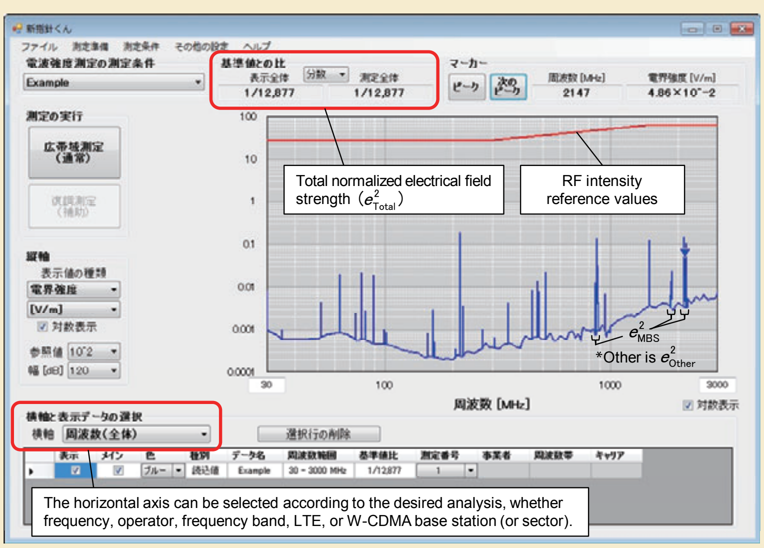

Figure 6　Screen shot of measurements from RF field intensity measuring equipment

this equipment according to these guides. The dominant factors affecting uncertainty are variations in the isotropism of the electrical field sensor, which affects accuracy of electrical field measurements, and fluctuations in the propagation paths as indicated in Section 2.3. Other factors include fluctuation in reflective losses in cable connectors and magnitude uncertainty in the spectrum analyzer and wireless channel decoder. As an example, we derive the uncertainty due to variations in the electrical field sensor isotropism, give the results, and calculate the expanded uncertainty, which is the total uncertainty for the overall measurement. To derive the uncertainty due to variation in the electrical field sensor isotropism, we measure the sensor gain using use a spherical surface scanning method. Taking the gain for the three sleeve dipoles arranged on three orthogonal axes to be g_x, g_y, and g_z respectively, the combined gain, g, over the three axes and its logarithm, $G\,[\text{dBi}]$ are given by:

$$g(\theta_i,\phi_j) = g_x(\theta_i,\phi_j) + g_y(\theta_i,\phi_j) + g_z(\theta_i,\phi_j) \quad (6)$$

$$G(\theta_i,\phi_j) = 10\log\left|g(\theta_i,\phi_j)\right| \quad (7)$$

Here, θ is the elevation, with range from $-\pi/2$ to $+\pi/2$, and ϕ is the azimuth, with range from $-\pi$ to $+\pi$. To evaluate the isotropism, we measured the gain at 91 and 181 points over θ and ϕ, respectively, at equal angle intervals. From these results, we calculated the sample standard deviation, S, as:

$$S = \sqrt{\frac{\sum_{j=1}^{n}\sum_{i=1}^{m}[G(\theta_i,\phi_j) - \overline{G}]}{mn-1}} \quad (8)$$

$$\overline{G} = \frac{\sum_{j=1}^{n}\sum_{i=1}^{m} G(\theta_i,\phi_j)}{mn} \quad (9)$$

Here, m and n are 91 and 181 respectively. This sample standard deviation is the measurement uncertainty caused by variation in the electrical field sensor isotropism. As shown in **Figure 7**, evaluating the frequency dependence of this uncertainty over the range from 500 MHz to 3 GHz indicates that it is below 2.6 dB.

Table 2 gives each of the main causes of uncertainty, their values, and also an example of calculating the expanded uncertainty, which is the overall total uncertainty estimated from these factors. In the table, the expanded uncertainty in the 2 GHz radio frequency band is 5 dB with a 95% confidence interval. In this case, adding 5 dB to the total normalized electrical field strength obtained from measurements confirms compliance, giving a conservative evaluation result.

5. Conclusion

We have described measurement equipment that we have developed to measure and visualize RF field intensity from base stations and other sources in a mobile base station environment, as stipulated in regulations enforcing the Radio regulation and related bulletins.

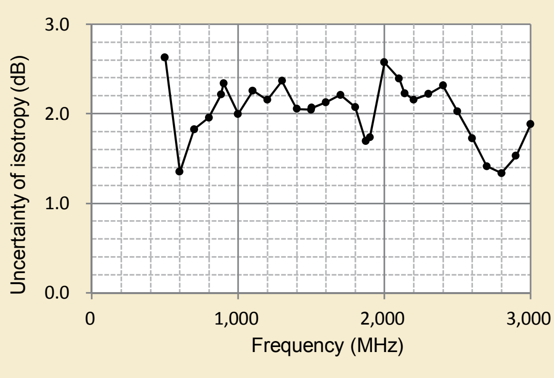

Figure 7 Frequency dependence of the uncertainty due to isotropy of the electrical field sensor

Table 2 Example of the expanded uncertainty of RF field intensity measurements in the 2 GHz band

Factor	Distribution function	Uncertainty a	Divisor d	$c^2 \times u^2$ *1 ($u = a/d$)
Electrical field sensor	Normal	2.23 dB	1.0	4.97
Reflective losses between RF switch and EM field sensor	U-quadratic	0.5 dB	1.14	0.13
RF Switch losses	Rectangular	1 dB	1.73	0.33
Reflective losses between analyzer and RF switch	U-quadratic	0.5 dB	1.14	0.13
Analyzer*2	Rectangular	1 dB	1.73	0.33
Propagation path	Rayleigh	3 dB	3.66	0.67
Cumulative standard uncertainty				2.56 dB
Expanded uncertainty (95% confidence interval)				5 dB

*1 c = 1.
*2 Spectrum analyzer and wireless channel decoder.

In particular, we discussed our method for obtaining peak-traffic RF field intensity values from combined LTE and W-CDMA base stations, even when traffic is fluctuating, and our implementation measuring the intensity of RF signals from any direction through the wide band from 30 MHz to 3 GHz, and achieving sensitivity below 1 mV/m. With this equipment, we have decreased the time required and simplified operation by automating the measurements, contributing to efficiency and reproducibility of RF field intensity measurements in installation and operation of base stations. We also evaluated the uncertainty in measurements made using this equipment, showing that the expanded uncertainty in the 2 GHz band was 5 dB with a 95% confidence interval. This equipment and the expanded uncertainty makes conservative evaluations of RF intensity for the purposes of checking compliance to regulations possible.

In the future, we will study further improvements to the equipment for various environments, such as supporting frequencies over 3 GHz and adding functionality to evaluate RF field intensity for 3GPP Rel. 9 and later.

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