3-4 Measurements of the Electromagnetic Field from a Mobile Phone Base Station

Soichi WATANABE and Lira HAMADA

A small isotropic 3-orthognal E-field probe and a measurement system with an antenna and a spectrum analyzer, defined as a relatively simple measurement equipment, were used for the investigation on the uncertainty of the measurement of E-field strength around a base station. Measurement values with the simple measurement equipment were then compared with the ideally estimated maximum values based on the measurements of the control signal of the W-CDMA and LTE base stations which is specified in an international standard. It was found that the measurement values of the simple measurement equipment agreed with the maximum valued based on the control signal within 12 dB, which suggests that the simple measurement equipment can be used for the compliance test of base station where the margin from the RF safety limit is larger than the uncertainty of the simple measurement estimated 22 dB from the deviation of the maximum value and the uncertainties due to the spatial and temporal variations.

1 Introduction

Exposure to excessively strong radio waves can have undesirable effects on the health of the human body. To prevent this, Radio Radiation Protection Guidelines for Human Exposure to Electromagnetic Fields (RRPG) [1] have been formulated in Japan. In RRPG, the effects (stimulation action) of nerves being stimulated by electric fields induced in the body (electric current density) is considered in frequency bands below 10 MHz, and thermal effects due to body temperature increase and so on caused by energy of radio waves absorbed in the body are considered in frequency bands above 100 kHz (both stimulus effect and thermal effect must be considered at 100 kHz to 10 MHz).

Cellular phones or mobile communication systems covered in this paper use radio waves in bands in the range from 700 MHz to 3.5 GHz. Guideline values for preventing thermal effects are formulated for this frequency band. Thermal effects are caused by thermal stress, which occurs when energy of radio waves is absorbed by the whole body, and by local heating, which occurs when energy of radio waves is absorbed locally in the human body. This paper covers exposure of entire human bodies to radio waves from mobile phone base stations located a relatively long distance away. Therefore, compliance with guideline values for preventing effects of whole body heating must be confirmed.

The method of evaluating compliance with RRPG with respect to fixed wireless equipment such as mobile phone base stations is stipulated in a report by the Telecommunications Technology Council of the Ministry of Internal Affairs and Communications (MIC) [2] and a MIC Notification [3]. The IEC standard [4] was also developed to establish a method to evaluate electromagnetic fields around mobile phone base stations as an international standard.

The international standard specifies a method for evaluating human body exposure to radio waves of the maximum possible strength considered, while ensuring reproducibility, for recent developments of mobile phone systems. In particular, it is known that radio wave strength from mobile phone base stations varies depending on communication conditions, and there is a possibility that the maximum electromagnetic field strength cannot be measured in a short time measurement. Therefore, the international standard uses a method for estimating the maximum electromagnetic field strength by measuring the strength of a control signal transmitted with constant strength regardless of the communication conditions. However, information necessary for measuring the control signal and estimating the maximum electromagnetic field strength from the control signal strength is basically only known to the communication carrier, and there is a need for an alternative method to evaluate compliance objectively by a third party.

Also, it is known that radio waves from base stations fluctuate greatly in space. To confirm compliance with RRPG, it is feasible to use the average of the electromagnetic field strength in the space occupied by the human body, but the spatial average evaluation method (evaluation points) differs in each country. The international standard also only lists the spatial average evaluation points specified in each country, a situation that is not consistent internationally.

Therefore, this research investigated the feasibility of compliance evaluation by a relatively simple measurement system such as a small probe for measuring tri-axial isotropic electric fields (hereinafter referred to simply as a "probe"), and a combination of an antenna and a spectrum analyzer. By using these measuring devices, temporal and spatial fluctuation was evaluated while measuring electric field strength around the base station, and uncertainty sources were investigated. Furthermore, in the case where there is a sufficiently large margin for values of RRPG, it was verified whether evaluation of compliance with the guidelines is possible in a short time and by a simple procedure.

2 Study of average space for the measurement of electromagnetic fields around the base station

2.1 Method

Measurement data was obtained from the Report on Survey of Electromagnetic Fields around Base Stations by the MIC[5]. Effects of the difference in the number of measurement points for the spatial average was investigated. The measurement method in this survey is described below.

2.1.1 Measurement device

A broadband horn antenna (double ridged guide antenna: EMCO 3115) was used as a measuring antenna. This antenna was attached to a fiber reinforced plastic pole, and connected to a spectrum analyzer (Anritsu MS2721A). This measurement system was mounted on a plastic cart. Figure 1 shows the general appearance of the measurement device [5]. The resolution bandwidth (RBW) of the spectrum analyzer and so on were set as follows according to the signals (modulation method) to be measured.

PDC

The Personal Digital Cellular (PDC) system is used in the second generation mobile phone system (2G) in Japan. The mobile-phone service using PDC ended (shifted to the third generation mobile phone systems (3G)) in 2012. The PDC system uses a Time Division Multiple Access (TDMA) modulation system, and the bandwidth per channel in Japan is 25 kHz (full rate system). Therefore, the RBW of the spectrum analyzer was set to 30 kHz, and the spectrum strength of the frequency range including all the channels in each frequency band (800 MHz band or 2 GHz band) transmitted was measured at the base station. For the downlink signal from the base station, the signal strength varies depending on the traffic state; therefore, the control channel which is not affected by the traffic state was measured.

W-CDMA

The Wideband Code Division Multiple Access (W-CDMA) system is used in 3G system in Japan. The 5 MHz bandwidth is used in Japan. On the other hand, the RBW of the spectrum analyzer used in this measurement was set between 10 Hz and 3 MHz, and cannot cover the bandwidth of the W-CDMA signal. Therefore, the frequency range over the signal bandwidth was swept with a constant RBW setting (suitably set between 10 and 300 kHz), and the value integrated over the signal bandwidth was used as the measured electric field strength. The control channel of the W-CDMA signal is also diffused in the bandwidth; therefore, in a spectrum analyzer not equipped with a dedicated decoder, it is impossible to measure only a control channel that is not affected by the traffic conditions. Therefore, the max-hold values for 1 minute were used.

2.1.2 Measurement sites

Base stations in five suburban areas and five urban areas were selected. Measurements were taken at regular

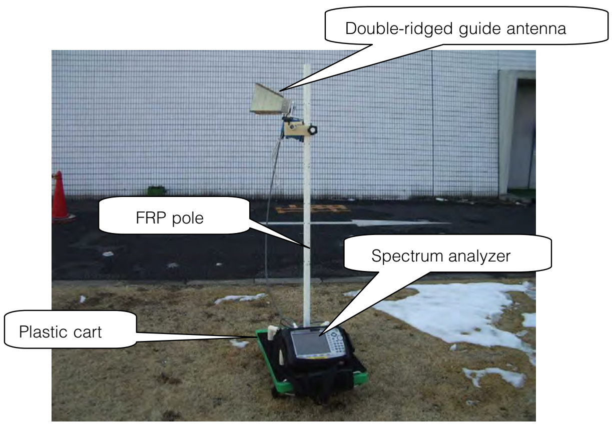


Fig. 1 General appearance of measurement equipment (photo from [5])

intervals along the main beam direction of the selected base stations. At this time, the measuring antenna was fixed at a height of 1.5 m above the ground. Measurements were taken at 10 cm intervals from 10 cm to 200 cm above the ground plane at the point where the maximum electric field strength was measured at 1.5 m height. Figure 2 shows a diagram of the measurement site [5].

2.1.3 Spatial average points

As points for spatial averaging, we compare and investigate for the 20 points specified in MIC Notification No. 300 [3], and the 3 points prescribed in the CENELEC standard [6] and so on. All these measurement points are used to evaluate the spatial average of an adult standing upright on the ground. Figure 3 shows each evaluation point.

2.2 Measurement results

Figure 4 shows the spatial average value of the squared electric field strength value around the base station (800 MHz band) in five suburban and five urban areas. It is shown that the measurement result fluctuates by two orders of magnitude (20 dB) or more, depending on the measurement location. On the other hand, it is shown that there is a small difference in measurement values due to the difference between the spatial average points (20 points and 3 points).

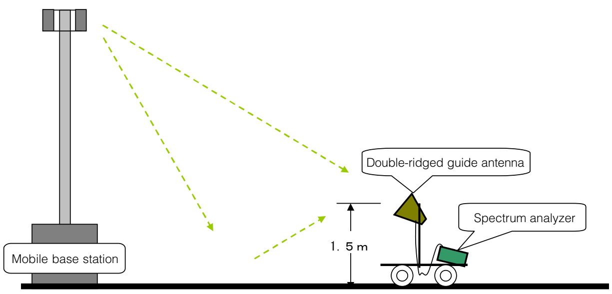


Fig. 2. Measurement site (diagram from [5])

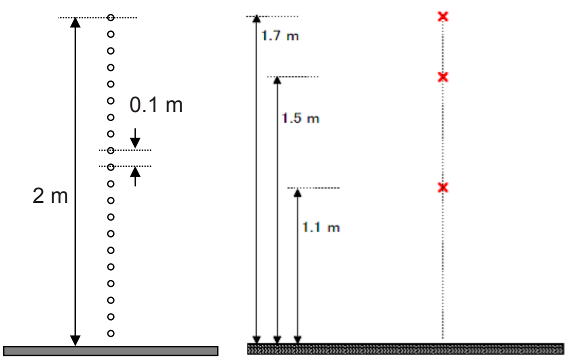


Fig. 3 Spatial average points (left: 20 points (MIC Notification No. 300), right: 3 points (CENELEC standard and so on.))

Figure 5 shows the deviation (based on 20 points) of the spatial average of squared electric field strength values at the spatial average point. For the five suburbs, the spatial average value of the 3 points is roughly equal to or greater than the spatial average value of 20 points, which indicates that overestimation is at most 60%. On the other hand, for four urban areas (urban A to D), the 3 points spatial average value was overestimated (24 to 56%) with respect to the spatial average value of 20 points, but one location (urban E) was greatly underestimated (-40%).

Figure 6 shows the spatial average of squared electric field strength values around the base station (2 GHz band) at two suburban and four urban locations. It is shown that the measurement results fluctuate by approximately one order of magnitude (10 dB) depending on the measurement location. On the other hand, it is shown that the differences in measurement values due to the difference between the spatial average points (20 points and 3 points) is smaller than the variation of the measurement location. These tendencies are similar to the results in the 800 MHz band (Fig. 4).

Figure 7 shows the deviation (based on 20 points) of the spatial average of squared electric field strength values at different spatial average points. For the suburbs, it is shown that the 3 points spatial average value is roughly equal to or greater than the 20 points spatial average value, with a maximum overvaluation of 32%. On the other hand, for urban areas, the 3 points spatial average value varied in the range of -38% to 42% with respect to the spatial average value of 20 points.

2.3 Discussion

2.3.1 Comparison of spatial average values

In evaluation of compliance with RRPG [1], it is feasible to implement evaluation using the spatial average of the electromagnetic field strength guideline values. These values correspond to the basic guideline values indicated by the whole body average SAR, which is an index of the effects of whole body heating. This is based on the assumption that the whole body average SAR value correlates with the incident electromagnetic field strength averaged over the whole body. The average of 20 points specified by MIC Notification No. 300 [3] is the average at intervals of 10 cm in the direction of body length. The highest point of the average point is 200 cm, which is much higher than the average height of a Japanese person. This arrangement was made to take account of the fact that the vertical strength distribution of radio waves propagating from an antenna

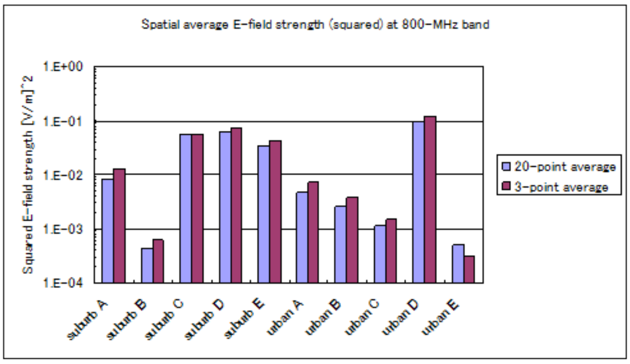


Fig. 4 Spatial average of squared electric field strength values (800 MHz band) around base stations in five suburban and five urban areas

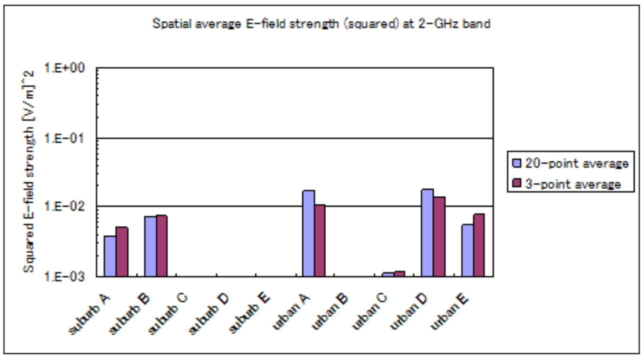


Fig. 6 Spatial average of squared electric field strength values (2 GHz band) around base stations in two suburban and four urban areas

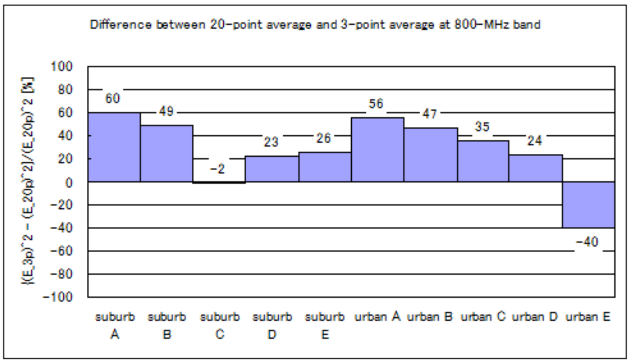


Fig. 5 Comparison of spatial average of squared electric field strength values (800 MHz band) around base stations in five suburban and five urban areas (3 points average value compared to 20 points average value)

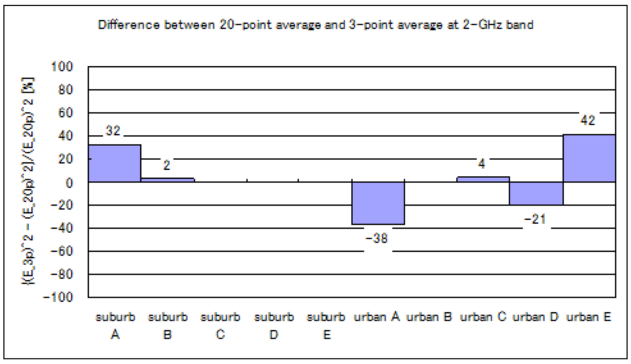


Fig. 7 Comparison of spatial average of squared electric field strength values (2 GHz band) around base stations in two suburban and four urban areas (3 points average value compared to 20 points average value)

in a high place is more intense. Also, the interval of 10 cm is specified in consideration of the spatial variation of radio waves (standing wave distribution and so on.) at frequencies of approximately 300 MHz or higher.

Considering the above, ideally, when spatial averaging of the electromagnetic field strength measurement value is performed, it is necessary to take measurements within the space corresponding to the entire human body at intervals that are sufficiently smaller than the fluctuations of the electric field strength. In the evaluation method of Japan, the average value of 20 points is set at 10 cm intervals, but in the European standard [6] and so on, the average value of 3 points is used. In the case of a 3 points average value, since there are a small number of evaluation points, the measurement time can be shortened. However, it is necessary to confirm whether the 3 points average value appropriately represents the entire body average value.

In this study, electric field strength measurements were carried out on mobile phone base stations in five suburban and five urban areas, and the 20 points average value and the 3 points average value were compared. As a result, in the suburbs, the average of the 3 points generally exceeded the average value of 20 points, indicating the possibility of being valid from the viewpoint of evaluation of compliance with RRPG. On the other hand, it has been shown that the average of 3 points in urban areas is underestimated by up to 40% with respect to the average value of 20 points, showing the need for careful investigation of the validity of applying 3 points values to electric field strength measurements around base stations.

Figures 8 and 9 show the distribution of the electric field strength in the height direction at each measurement location. At the urban area measurement location (urban E) where the 3 points average value is underestimated in the 800 MHz band (Fig. 8), it is shown that the electric field strength decreases greatly at heights higher than 150 cm. On the other hand, at measurement locations in urban areas (urban A and urban D) where the 3 points average value is underestimated in the 2 GHz band (Fig. 9), the electric field strength is shown to be roughly equal to or greater than that of the high place even at low places near the ground plane. All these are measured results in urban

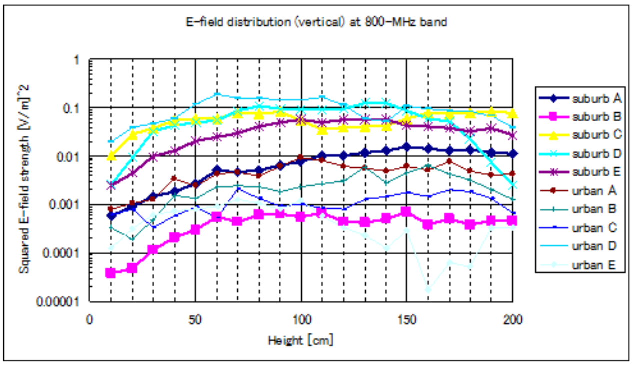


Fig. 8 Vertical spatial distribution of squared electric field strength at each measurement point (800 MHz band)

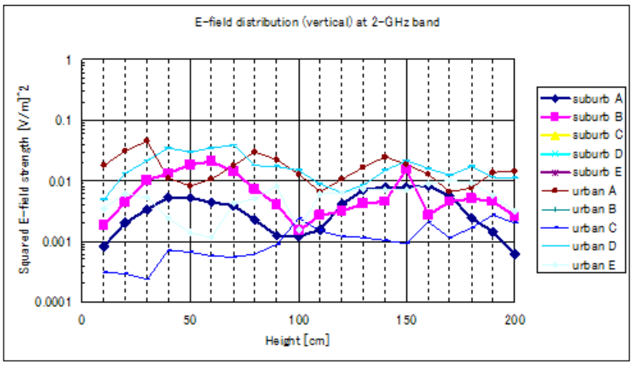


Fig. 9 Vertical spatial distribution of squared electric field strength at each measurement point (2 GHz band)

areas, therefore when the electric field strength at a high place decreases locally due to effects of surrounding reflectors and the like. Conversely, when electric field strength at the low place is enhanced, it is suggested that the 3 points average value is underestimated compared to the entire body average value (20 points average value). In these measurement results, the electric field strength at a high place decreases in the 800 MHz band (Fig. 8) and the electric field strength in the low place increases in the 2 GHz band (Fig. 9); it is unclear whether this tendency depends on the frequency difference. In the future, in addition to obtaining further measurement samples , theoretical investigation of radio wave propagation characteristics in each frequency band will be necessary.

2.3.2 Uncertainty

Uncertainty sources in these measurements are listed below.

- Antenna
  - Antenna calibration factor
  - Maximum pointing direction
  - Installation position
- Spectrum analyzer
  - RBW
  - Max hold (average time)
- Variation in output from base station
  - Output control
  - Traffic fluctuation
- Other
  - Scanning device
  - Fading
  - Ambient reflection
  - Weather (temperature, humidity)

Among the above, the following are systematic uncertainties that do not affect results of comparison between the 20 points average value and 3 points average value: antenna calibration factor, installation position, RBW, output control and weather. After considering uncertainty factors other than these, it is necessary to judge the validity of the spatial average value considered in the previous section.

The IEC Technical Report [7] presents an example where extended uncertainty (k = 2) of the electric field strength measurement is approximately 3 to 5 dB. The uncertainty of the result of comparison between the 20 points average value and the 3 points average value is thought to be smaller, but it may be comparable to the underestimation (maximum 40% (2.5 dB)) indicated in this study. In that case, it should be judged that it is roughly similar, not underestimated.

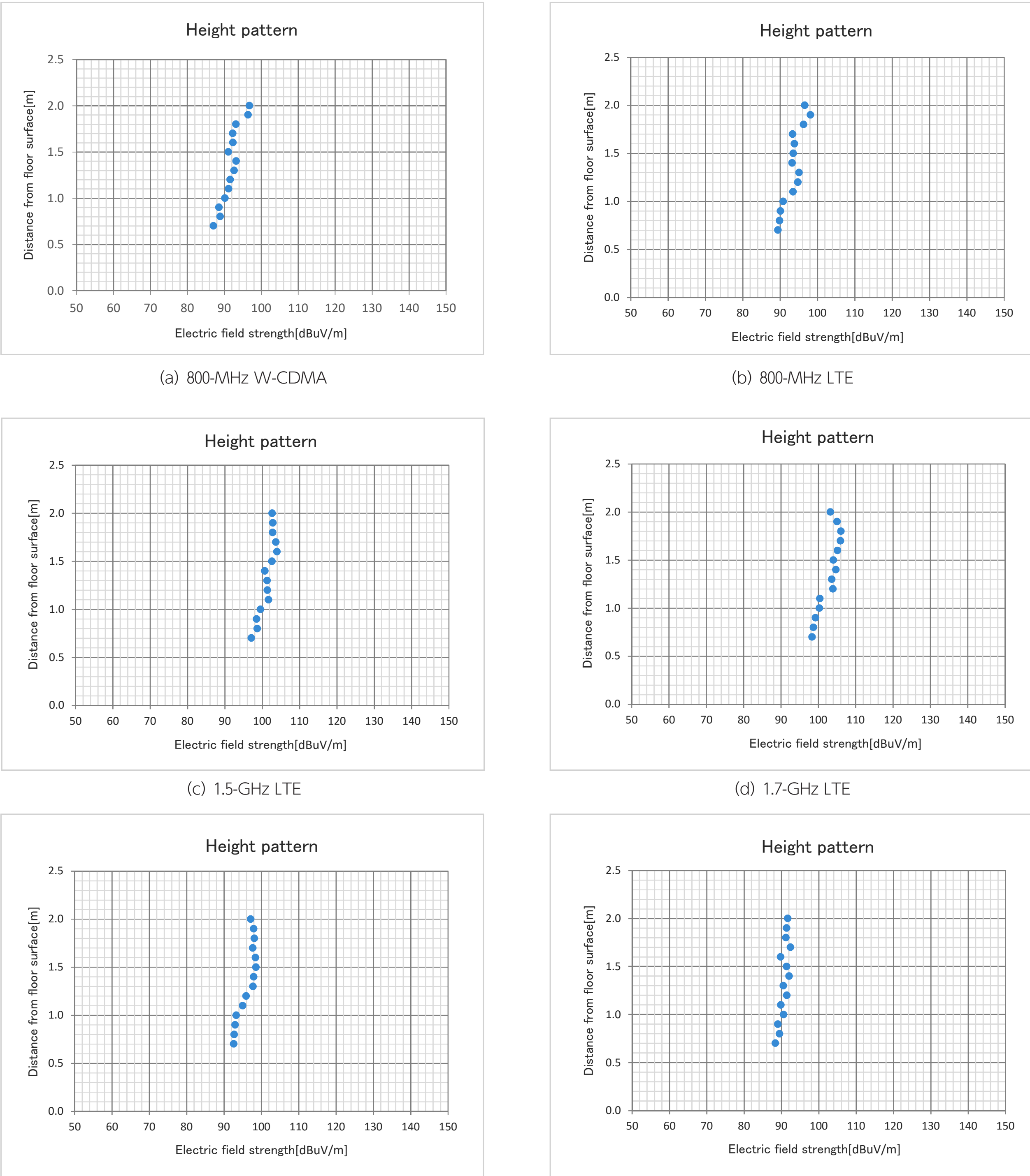
The squares of the values of RRPG (electric field strength guideline values) is 2.0 × 10 $(4\ \mathrm{V/m})^2$ at 800 MHz and 3.8 × 10^4 $(\mathrm{V/m})^2$ at 2 GHz. The measurement results in this study (up to 10^{-1} $(\mathrm{V/m})^2$) have a margin of 5 orders of magnitude (50 dB) or more. Therefore, when there is sufficient margin against the allowable value, it may be concluded that the 3 points average value gives almost the same evaluation result as the spatial average value by more average points. This will be discussed again in another section (investigation on simple evaluation using the probe and so on.).

2.3.3 Specification of spatial average values in international standards

IEC 62232 [4] and ITU Recommendation K.61 [8] are international standards concerning electromagnetic field measurement methods around fixed wireless stations such as mobile phone base stations. Both standards adopt the 20 points spatial average method used in Japan, along with other spatial average methods (3 points, 6 points, 9 points). However, it cannot be said that the spatial average has been studied sufficiently for any of the standards, and the spatial average methods adopted by the regulatory authorities of each country are listed.

Unlike mobile phone terminals, base stations are only operated and supervised in each country; therefore, differences in evaluation methods do not affect product exports and so on. However, due to growing international interest in the health effects of radio waves, the use of different spatial average methods in each country may not be appropriate for risk management of mobile phone systems operated internationally with the same specifications.

Therefore, based on the situation of each country, in order to ensure international consistency of appropriate spatial average points based on objective knowledge, it is desirable to conduct an evaluation study on spatial average in an international framework.



(a) 800-MHz W-CDMA (b) 800-MHz LTE

(c) 1.5-GHz LTE (d) 1.7-GHz LTE

(e) 2-GHz LTE (f) 2-GHz W-CDMA

Fig. 10 Height characteristics of electric field strength measurement around base stations of 3G mobile phones (W-CDMA) and 4G mobile phones (LTE) (indoor measurements)

Note that in creating the ITU Recommendation [8], at the ITU-T/SG5 meeting , which was deliberating the recommendation proposal, the evaluation data investigated in this study was contributed, the validity of the 20 points average values were clarified, and the ITU Recommendation reflected the spatial average method adopted in Japan.

2.3.4 Application of these research study results to other mobile phone systems

Application of this study to the 2G mobile phone systems (PDC) and 3G mobile phone systems (W-CDMA) is under consideration. Services of 2G mobile phone system are ending in Japan in 2016, but these evaluation results may be a reference for evaluations of GSM mobile phone systems in Europe and so on adopting the TDMA modulation system, same as PDC. However, the average point for the spatial average value seems to be affected more strongly by the frequency than the modulation method.

The 3.5th/4th generation mobile phone systems (4G/LTE) have commercial services that began in 2009. They use an OFDM modulation method for downlink signals. Other services also started, such as Carrier Aggregation (CA) that simultaneously uses different frequency bands, and the TD-LTE method that shares the same frequency band for uplinks and downlinks. It seems that temporal and spatial fluctuations of radio waves from these base stations are much different than in 3rd generation mobile phone systems. Therefore, in the future, it seems necessary to investigate in detail the spatial distribution of the electromagnetic field strength around base stations of 4G mobile phone systems.

The height pattern measurement of the W-CDMA and the LTE signals indoors is carried out in the following section (investigation of simple evaluation using the probe and so on); Fig. 10 shows this result. Although there is no clear tendency regarding frequency and modulation method, it is shown that there is a fluctuation of approximately 10 dB. However, in Figs. 8 and 9, the measured value in the region near the floor surface, which is not measured in Fig. 10, shows a tendency to rapidly attenuate with respect to the measured value in the upper part. Therefore, in the future, it may be necessary to take measurements in low areas on the floor surface or outdoor areas around base stations of the latest mobile phone systems.

3 Investigation of average time in electromagnetic fields around base stations

3.1 Method

3.1.1 Small probe for measuring tri-axial isotropic electric fields

Electric field strength from a 3G mobile phone (W-CDMA) base station was measured using the probe (NARDA SRM-3000). The resolution bandwidth was set to 100 kHz, and the numerical value integrated over the signal bandwidth (5 MHz) was used as the measured value. A frequency span of 50 MHz was set, including the center frequency of the W-CDMA signal in the 800 MHz band and the 2 GHz band. The other settings were Auto.

The electric field probe was attached to a non-metallic pole, and installed at a position 1.5 m above the ground. Figure 11 shows the general setting.

3.1.2 System for measuring tri-axial electric fields using a broadband antenna

In addition to the small tri-axial electric field probe of the previous section, the electric field strength from the base station was measured using a system for measuring tri-axial electric fields (Field Nose manufactured by ARCS) equipped with a mechanism for rotating a broadband antenna (conical horn antenna). In this system, the conical

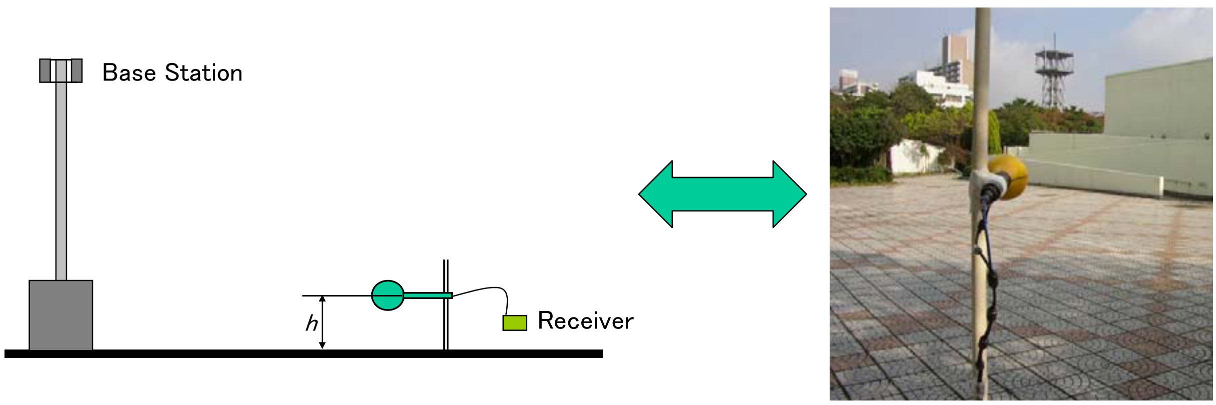


Fig. 11 Schematic showing the measurement of electric field strength around the base station using the electric field probe

Table 1 Time average of the electric field strength around a W-CDMA base station

Time	*10s*	*20s*	*30s*	*40s*	*50s*	*1min*	*2min*	*3min*	*4min*	*5min*	*6min*	*1h*	*24h*
Number of measurements	62	115	172	230	280	334	654	976	1299	1660	1940	174	1429
Average E-field [dB]	−0.4	−0.3	−0.2	−0.2	−0.3	−0.4	−0.3	−0.1	−0.1	−0.0	0	−4.0	−4.2

horn antenna is tilted 54 degrees and rotated at intervals of 120 degrees, to measure the strength of tri-axial isotropic electric fields.

The antenna is installed in a position approximately 0.5 m above the lower surface of the system. The antenna is stored in the dome, and it has specifications that enable measurements for a long time outdoors. Figure 12 shows photos of this system.

In the measurements, similarly to the probe, the RBW was set at 100 kHz and the numerical value integrated over the 5 MHz W-CDMA signal bandwidth was taken as the measured value.

3.1.3 Measurement sites

The measurement sites were set to be around mobile phone base stations that emitted W-CDMA signal (line of sight direction) in the suburbs of Tokyo. Long-term measurements were conducted at two different base station locations for 1 day (measurement site 1) or 1 week (measurement site 2).

In the case of the one week measurement (measurement site 2), measurements were taken during the average time up to 6 minutes, in 10 second intervals when using the probe, and 20 second intervals when using the broadband antenna tri-axial electric field measuring system. Measurements were also taken at 12 minute intervals at the same measurement sites during an average time of 1 hour or more.

Fig. 12 System for Measuring Tri-axial Electric Fields Using a Broadband Antenna (Left) and Conical Horn Antenna (Right) in the System

Note that in the results in the figures shown in the following sections, time average values are shown for each day from 1 to 7 days. For example, the 3rd day is not the time average value for 3 days; it shows the time average value for 1 day (24 hours) on the 3rd day.

3.2 Measurement results

3.2.1 Measurement site 1 (one day measurement by the probe)

The W-CDMA signal from the base station was measured for 24 hours by the probe (Fig. 11). Table 1 shows the electric field strength values averaged over the respective measurement durations. The measured values are normalized by the 6 minutes average value specified in RRPG Also, with respect to the average value over 1 hour and 24 hours, since there are a huge number of measurements, measured values between suitably selected periods are averaged. In the table, the number of measurement values used for each average time is also listed.

When the average time is varied from 10 seconds to 6 minutes, the fluctuations of the time average value are 0.4 dB or less, which is much smaller than due to spatial variation such as the measurement location and measurement height shown in the previous section. On the other

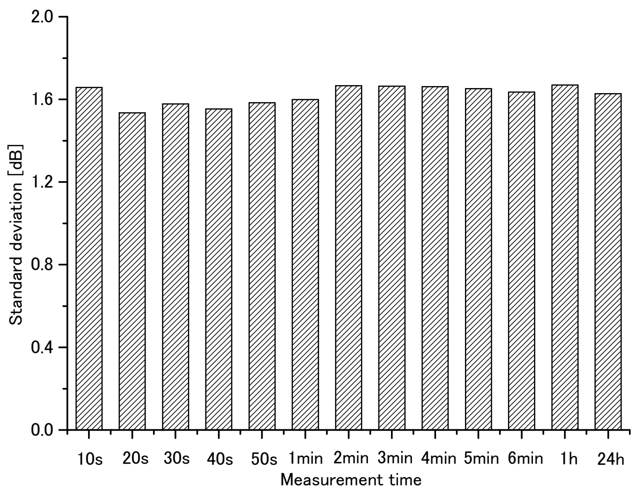


Fig. 13 Relative standard deviation of measured values for the average time of the electric field strength around the W-CDMA base station

hand, the value averaged over 1 hour or 24 hours is approximately -4 dB less than the 6 minutes average value.

Figure 13 shows the relative standard deviations of the measured values for each average time in Table 1. It shows that the standard deviations are approximately 1.6 dB in all these cases from 10 seconds to 24 hours.

3.2.2 Measurement site 2 (one week measurement by the probe and broadband antenna)

Figure 14 shows the time average values of the electric field strength around the W-CDMA base station. The results of tri-axial electric field measurements taken by the broadband antenna system indicated that when the time average value is shorter than 3 minutes, the value increases compared to the average value for 6 minutes; at 20 seconds it was approximately 3 dB greater than the 6 minutes average value.

On the other hand, when the average time was longer, it was within 1 dB of the average value for 6 minutes.

The results of tri-axial isotropic electric field measurements taken by the small probe revealed that when the average time was from 10 seconds to 6 minutes, the time average values were always within 0.5 dB of each other. On the other hand, when the average time was 1 day or more, it decreased by up to 2 dB or more compared to the 6 minutes average value on the first day.

Figure 15 shows the relative standard deviation of the measured values at the average times of Fig. 14. It shows that the standard deviations of the values measured by the system for measuring tri-axial electric fields using a broadband antenna (hereinafter referred to simply as the "broad-

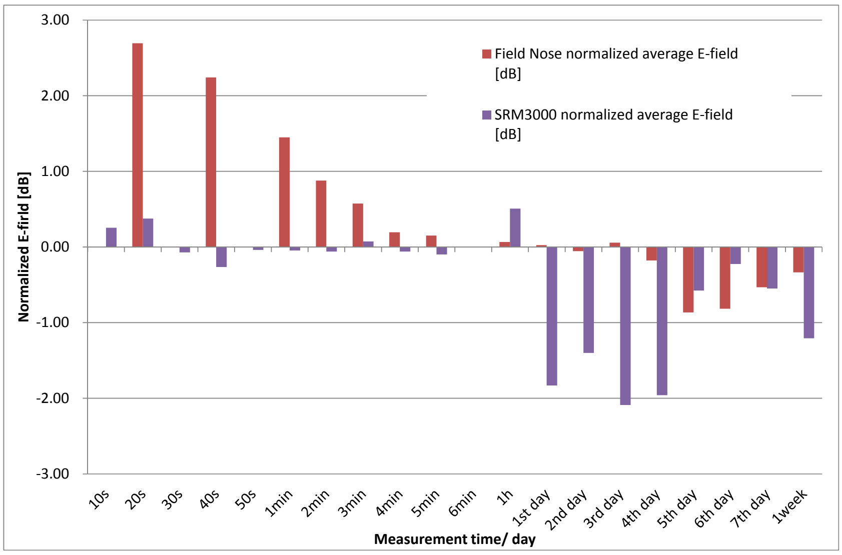


Fig. 14 Time average of electric field strength around the W-CDMA base stations (10 seconds to 1 week) (Red: Values measured by broadband tri-axial electric field measurement system. Purple: Values measured by the probe) (Normalized by 6 minutes average value)

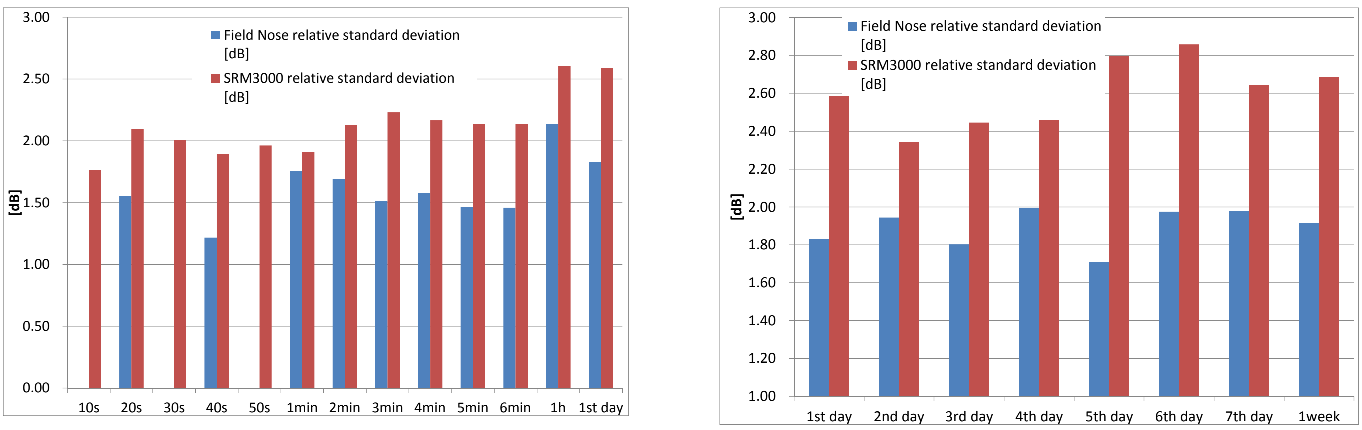


Fig. 15 Relative standard deviation of measured values in the average times of the electric field strength around the W-CDMA base station (Left: 10 seconds to 1 day. Right: 1 day to 1 week) (Blue: Values measured by broadband tri-axial electric field measurement system. Red: Values measured by compact tri-axial isotropic electric field probe)

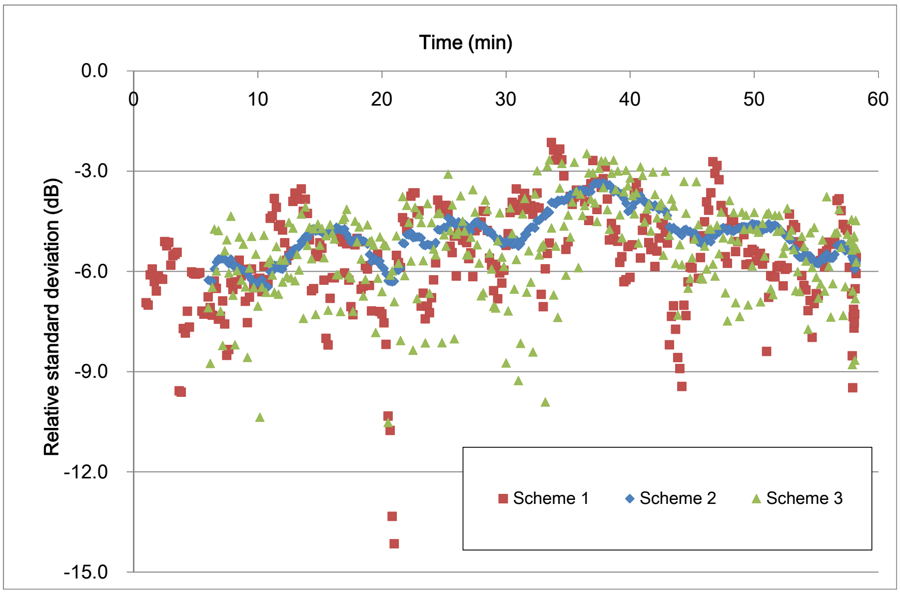


Fig. 16 Temporal fluctuations of standard deviation due to different sampling intervals / numbers of samples in measurements of electric field strength around the base stations by the probe. (Scheme 1: 7 samples (1 minute) at 10 second intervals. Scheme 2: 37 samples (6 minutes) at 10 second intervals. Scheme 3: 7 samples (6 minutes) at 1 minute intervals)

band antenna system") are approximately 0.5 dB smaller than the standard deviations of the values measured by the probe. Moreover, compared to the results in the previous section, it shows that the standard deviations of the measured values of the probe are approximately 1 dB larger. Furthermore, it was consistent in both measurement systems that the standard deviations at average times of 1 hour or more are approximately 0.5 dB greater than the standard deviations at average times from 10 seconds to 6 minutes.

3.3 Discussion

3.3.1 Time average over a short time

In the measurements by the probe, at both of the two base stations (site 1 and site 2), even at average times (10 seconds or longer) that were shorter than the 6 minutes average time specified in RRPG, time average values of the measured electric field strength were within 0.5 dB of the average value for 6 minutes. On the other hand, using the broadband antenna system at site 2, the measured values increased as the average time was shortened (for the average time of 20 seconds, it was approximately 3 dB greater than the average value for 6 minutes).

This is thought to be due to differences in measurement data processing in each measurement system. In the case of the probe, the time interval between data acquisition (data transfer from the probe reading device to the PC) was set to 10 seconds, but the measurement value is read at high speed inside the measuring device. It is conceivable that the measured values transferred to the PC are integrated (smoothed) over certain time spans. On the other hand, in measurements by the broadband antenna system, data transferred to the PC is considered to be values corresponding to the instantaneous values at the time of transfer. Therefore, as the average time becomes shorter, the number of acquired data becomes smaller, thus the measured values in the case of short average times seem to differ greatly from the average value for 6 minutes (in the case of the average time of 20 seconds, only one data measurement value). In measurements by the broadband antenna system of this study, measured values tend to increase as average time shortens, but these measurement results were at only one measurement site, thus further study may be necessary regarding whether this is a general tendency.

The W-CDMA signal waveforms fluctuate randomly, and their fluctuation speeds are sufficiently faster than the average time studied in this project. Therefore, the time averages investigated in this may be equivalent to investigating effects of the sampling number of signal waveforms fluctuating randomly and more rapidly. That is why Fig. 16 shows the results of evaluating standard deviations (standard deviation of the sample used for calculating the average value) in the case of changing the data acquisition intervals and average times (number of samples for calculating the average value) of the probe.

Figure 16 shows that Scheme 1 (10 second intervals &

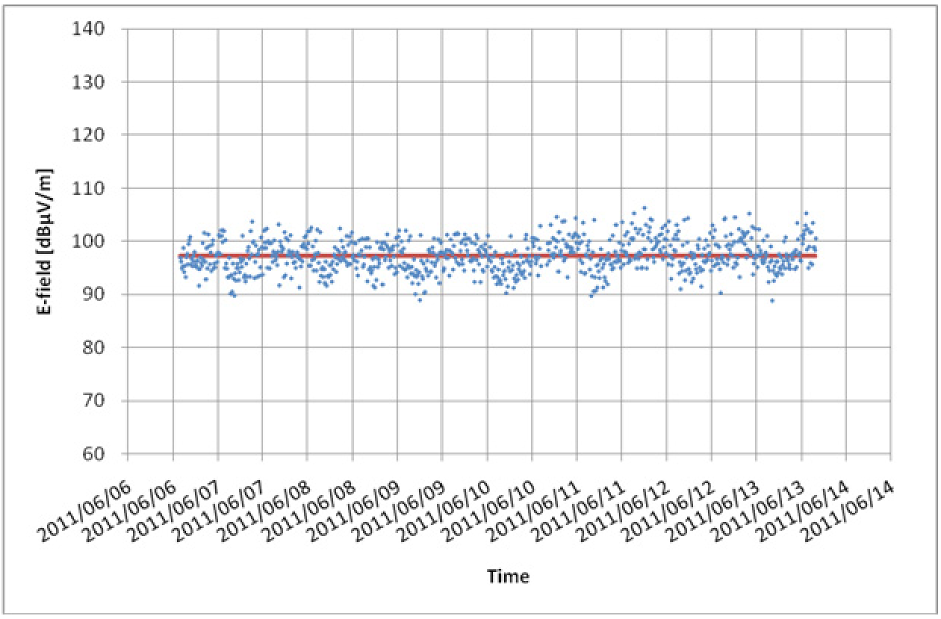


Fig. 17 Temporal fluctuations of measured values of electric field strength around W-CDMA base station by the small probe for measuring tri-axial isotropic electric fields

7 samples) and Scheme 3 (one minute intervals & 7 samples) with the same number of samples and different average times (data acquisition time intervals) have almost the same standard deviations. On the other hand, it shows that Scheme 2 (10 second intervals & 37 samples) has standard deviations that differ from Schemes 1 and 3 (Scheme 2 has smaller temporal fluctuations).

Therefore, in the electromagnetic field measurements around the W-CDMA base station, the data acquisition interval and the number of samples for calculating the time average values may be more important factors than the average time.

3.3.2 Time average over a long time

At both measurement sites, values fluctuated more when averaging for longer than 6 minutes than when averaging for 6 minutes. The cause of this may be measurement errors such as drift of the measurement system and fluctuations in the output level due to fluctuations in communication traffic of the mobile phone base station. This is why Fig. 17 shows temporal fluctuations of the electric field strength measurement values from the probe at Site 2.

In Figure 17, clear (approximately 10 to 20 dB) daily cycle fluctuations can be confirmed. Therefore, large fluctuations of the time average value over a long time may be largely caused by changes in the output level of the base station due to communication traffic fluctuations and so on. At the measurement site and measurement period in Fig. 17, fluctuations during the weekend (2011/6/11-12) tended to be slightly larger than on weekdays. However, since these measurements were conducted in Tokyo three months after the Great East Japan Earthquake, it should be noted that they include effects of special circumstances (planned blackouts and so on.) at that time.

3.3.3 Time average specifications in international standards

In the IEC international standard [4] for evaluation of strength of electromagnetic fields around base stations, it is prohibited to perform time averaging when evaluating compliance with values of RRPG. That is, the electromagnetic field strength not dependent on the output control state of the base station such as the control channel signal should be measured, the theoretically maximum electric field strength is calculated, and compliance with RRPG value is evaluated. On the other hand, it also refers to the usefulness of using time average when acquiring data for understanding the exposure situation in the measurement environment.

The ITU Recommendation [9] on the electric field strength evaluation method to be performed before starting operation of individual base stations does not clearly specify the average time. However, based on electric field strength measurement data around base stations at seven sites in the Appendix, there is a description that an average time of approximately 1 minute is desirable. That data is a measurement example in Korea (CDMA2000), which are measurement results with the same probe as in this study. The measurement results shown in that Recommendation

Table V.1 – Comparison of electric field strength (in dBµV/m) for different averaging times

Time (s) / BS No.	360	180	60	40	10
1	109.14	109.14	109.16	109.14	109.08
2	109.80	109.79	109.79	109.79	109.80
3	107.07	107.07	107.09	107.07	107.11
4	111.59	111.55	111.60	111.63	111.81
5	92.56	92.36	92.34	92.33	92.56
6	90.41	90.28	90.76	90.84	90.74
7	97.38	97.26	97.39	97.40	97.67

Fig. 18 Results of electric field strength measurements by a small probe for measuring tri-axial isotropic electric fields around a mobile phone base station in Korea (table from [9])

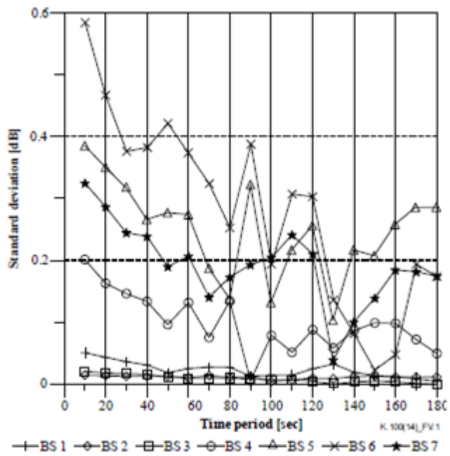


Figure V.1 – SD for different averaging times compared with that of 360 s

Fig. 19 Standard deviation of the average time spent for electric field strength measurements using the probe around the mobile phone base station in Korea (from [9])

are shown in Figs. 18 and 19.

In Fig. 18, as in the measurement results of the probe in this study (Table 1, Fig. 14), the average values for times less than 6 minutes match very well (within approximately 0.3 dB) with the average value for 6 minutes. On the other hand, in Fig. 19, the standard deviation increases when the average time is short, showing a tendency similar to the measurement results of the broadband antenna system in this study (Fig. 14). However, the absolute values of the standard deviations are smaller by 2 dB or more than in the case of this study, and even at its maximum it is a level sufficiently lower than 1 dB. This may be due to effects of difference in the methods of data transfer to the PC and so on for calculating time average values, and difference in the modulation methods of the base station signals measured.

In either case, the measured electric field strength is several tens of dB lower than values in RRPG (approximately 155 dBµV/m). Therefore, further investigation may be needed for reducing the averaging time requirement.

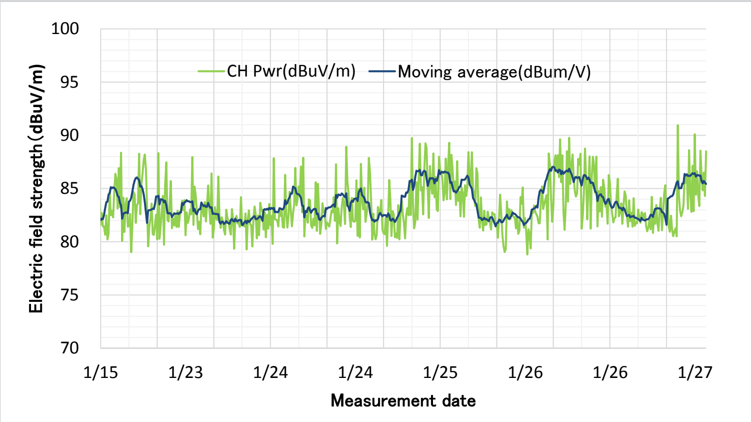
3.3.4 Application of these research results to other mobile phone systems

Signals from 4G mobile phone base stations and latest wireless LAN systems adopt the OFDM modulation method, which is different from the W-CDMA covered in this study. However, since random temporal signal waveforms have common characteristics, general characteristics depending on the number of samples may be similar. On the other hand, it is known that OFDM modulation systems have instantaneous peak values (peak average ratio (PAR) values) that are larger than in CDMA, and the standard deviations (measurement uncertainty) of the time average values are expected to be larger.

Therefore, the tables below show results of measuring the surrounding electric field strength from base stations (2 places), which use the LTE and W-CDMA systems, in the suburbs of Tokyo for 9 to 12 days. These measurements used the broadband antenna and spectrum analyzer described in Section **4** below. Measurements were taken each 12 minutes. The spectrum analyzer was set to max hold and refreshed each 12 minutes. The figure also shows the moving average value of 10 measurement data (120 minutes). No significant difference was observed between the measurement sites or the LTE method and the W-CDMA method, and it shows the same tendency as in Fig. 17.

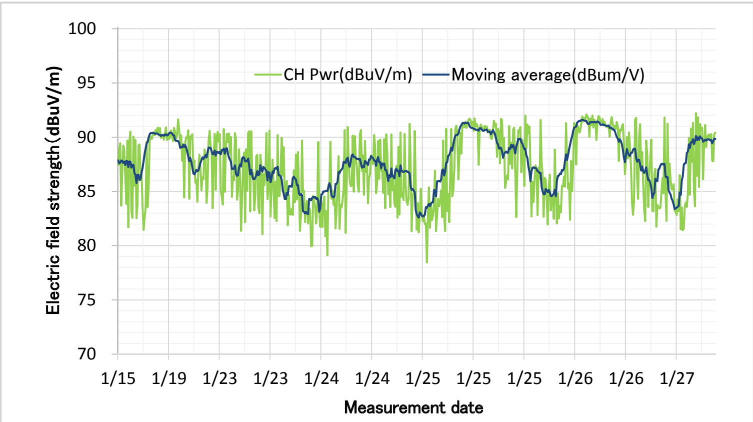
The deviation greatly exceeds 20 dB in some cases, but it is a case where the measured value becomes extremely low, and since it is unnaturally lowered from the surrounding data at the same time, the problem of fetching data of the measuring system may be the cause. In addition, since the deviations of moving average values at 10 points are less than 10 dB, it is possible to compress the fluctuation range over a long period of time by averaging the data over a certain period of time. However, since the time average value of 6 minutes is applied in RRPG, it should be noted that characteristics of the moving average value for 120 minutes carried out in this study cannot be directly applied to compliance evaluation tests.

In 4G mobile phone systems and next generation (5G) mobile phone systems, it is expected that time variation characteristics will become more complex due to the widespread use of TD-LTE systems, CA, MIMO and so on. Therefore, it may be necessary to continue detailed investigations.



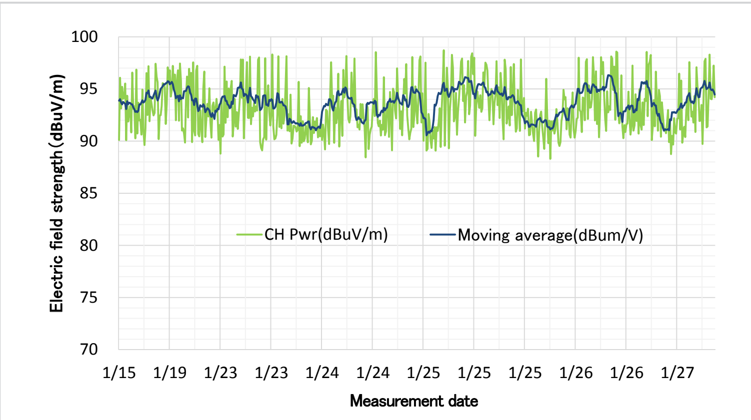
Maximum	91dBμV/m
Minimum	79dBμV/m
Deviation	12dB
Maximum (moving average)	87dBμV/m
Minimum (moving average)	81dBμV/m
Deviation (moving average)	6dB

(1) 800 MHz band CDMA



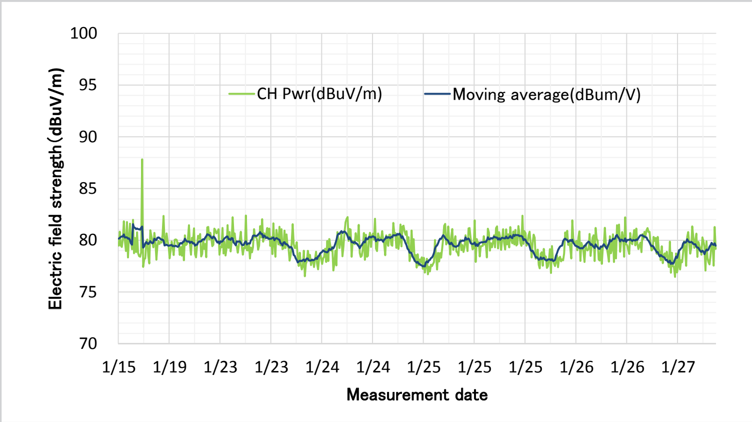
Maximum	92dBμV/m
Minimum	78dBμV/m
Deviation	14dB
Maximum (moving average)	92dBμV/m
Minimum (moving average)	83dBμV/m
Deviation (moving average)	9dB

(2) 800 MHz band LTE



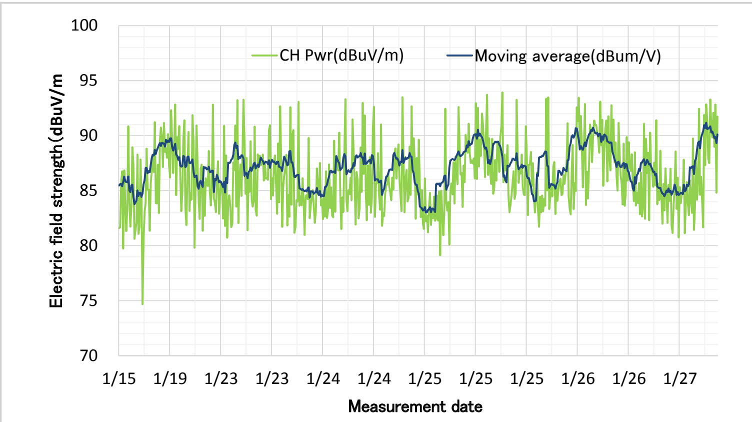
Maximum	99dBμV/m
Minimum	88dBμV/m
Deviation	10dB
Maximum (moving average)	96dBμV/m
Minimum (moving average)	91dBμV/m
Deviation (moving average)	5dB

(3) 1.5 GHz band LTE



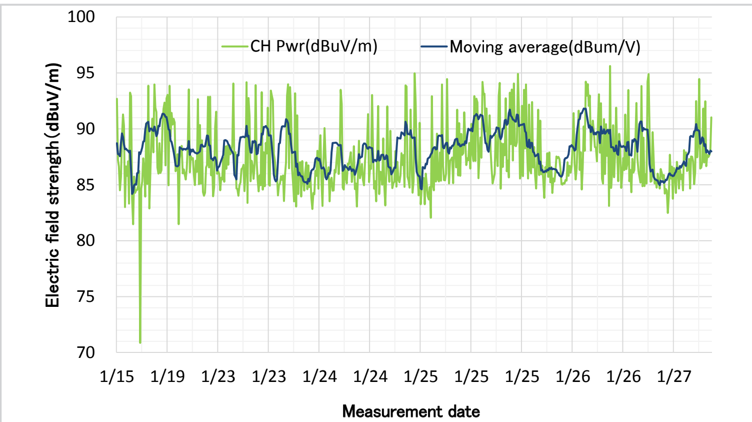
Maximum	88dBμV/m
Minimum	76dBμV/m
Deviation	11dB
Maximum (moving average)	82dBμV/m
Minimum (moving average)	77dBμV/m
Deviation (moving average)	5dB

(4) 1.7 GHz band LTE



Maximum	94dBμV/m
Minimum	75dBμV/m
Deviation	19dB
Maximum (moving average)	91dBμV/m
Minimum (moving average)	83dBμV/m
Deviation (moving average)	8dB

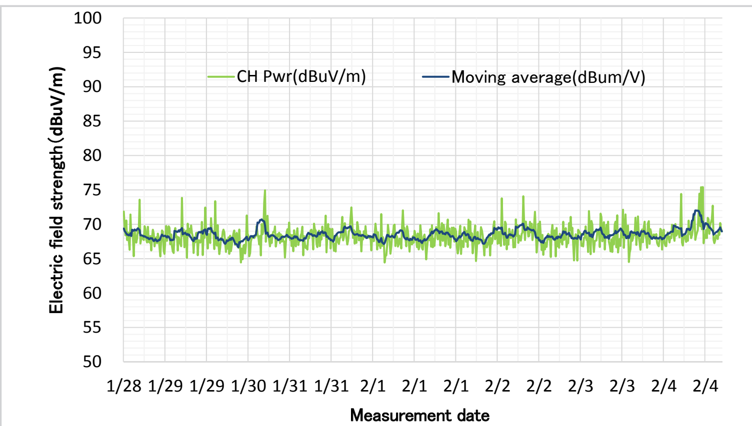
(5) 2 GHz band LTE



Maximum	96dBμV/m
Minimum	71dBμV/m
Deviation	25dB
Maximum (moving average)	92dBμV/m
Minimum (moving average)	84dBμV/m
Deviation (moving average)	8dB

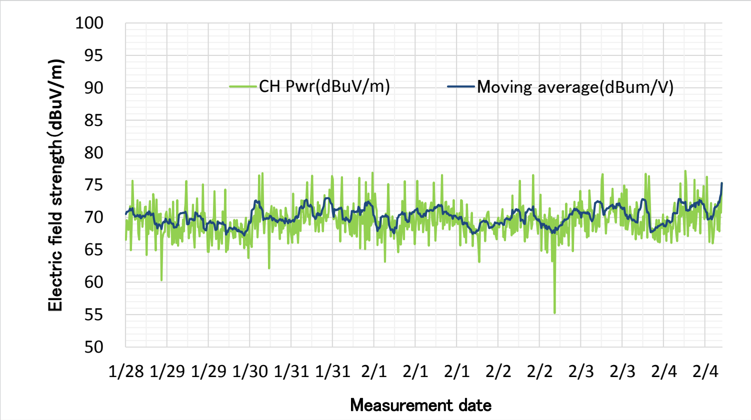
(6) 2 GHz band W-CDMA

(A) Measurement results at site A (indoors)



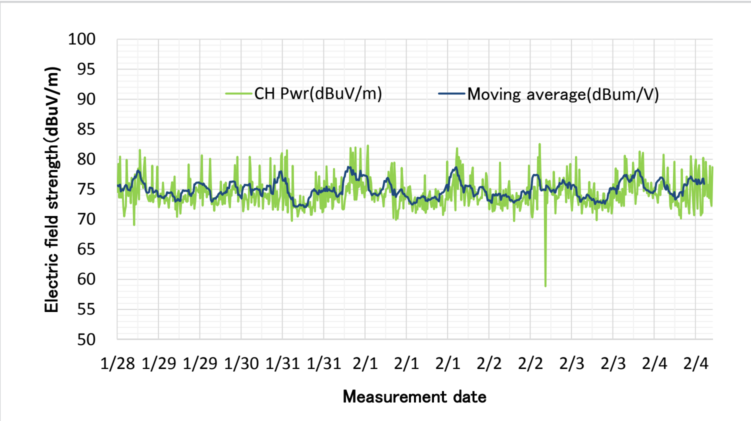
Maximum	75dBμV/m
Minimum	64dBμV/m
Deviation	11dB
Maximum (moving average)	72dBμV/m
Minimum (moving average)	67dBμV/m
Deviation (moving average)	5dB

(1) 800 MHz band W-CDMA



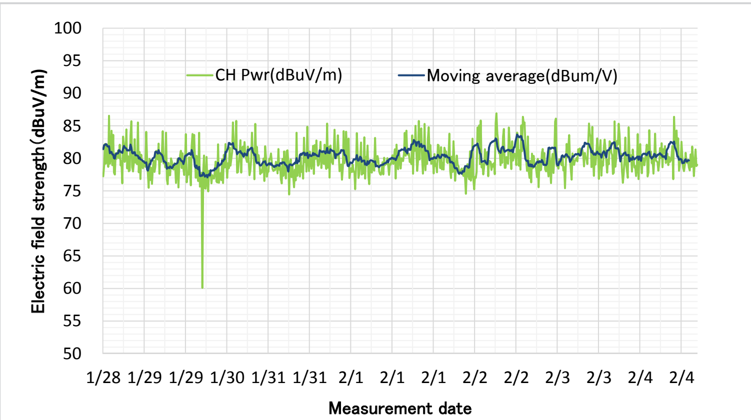
Maximum	77dBμV/m
Minimum	55dBμV/m
Deviation	22dB
Maximum (moving average)	75dBμV/m
Minimum (moving average)	67dBμV/m
Deviation (moving average)	8dB

(2) 800 MHz band LTE



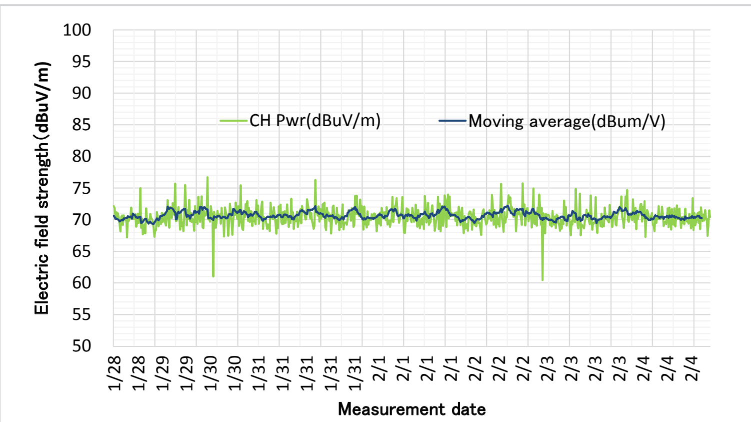
Maximum	83dBμV/m
Minimum	59dBμV/m
Deviation	24dB
Maximum (moving average)	79dBμV/m
Minimum (moving average)	72dBμV/m
Deviation (moving average)	7dB

(3) 1.5 GHz band LTE



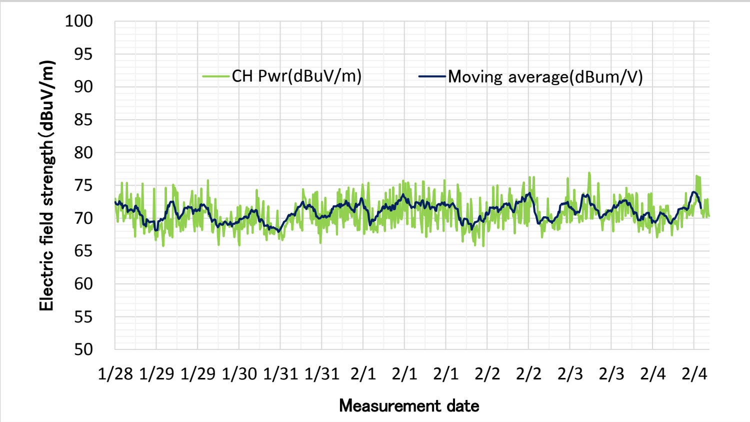
Maximum	87dBμV/m
Minimum	60dBμV/m
Deviation	27dB
Maximum (moving average)	84dBμV/m
Minimum (moving average)	77dBμV/m
Deviation (moving average)	7dB

(4) 1.7 GHz band LTE



Maximum	77dBμV/m
Minimum	60dBμV/m
Deviation	16dB
Maximum (moving average)	72dBμV/m
Minimum (moving average)	69dBμV/m
Deviation (moving average)	3dB

(5) 2 GHz band LTE



Maximum	77dBμV/m
Minimum	66dBμV/m
Deviation	11dB
Maximum (moving average)	74dBμV/m
Minimum (moving average)	68dBμV/m
Deviation (moving average)	6dB

(6) 2 GHz band W-CDMA

(B) Measurement results at site B (indoors)

Fig. 20 Results of long-term measurements of electric field strength around mobile phone base stations (2 locations), which use the W-CDMA and LTE systems. CH Pwr value is the max hold value for 12 minutes. The moving average value is the average of measured values at 10 consecutive points (120 minutes). Both of these measurement locations were indoors.

4 Study on simple evaluation using the small probe for measuring tri-axial isotropic electric fields

4.1 Method

4.1.1 Measuring devices

Measurements of electric field strength were taken by two measurement systems, in which the probe (SRM-3000 manufactured by NARDA) or a broadband antenna (conical dipole antenna: PCD8250 manufactured by ARC) was connected to a spectrum analyzer (MS2713E manufactured by Anritsu Corporation).

In both measurement systems, the RBW setting was 100 kHz, and was integrated over the signal bandwidth. Also, max hold was conducted during approximately 20 seconds. Under these conditions, measurement data was acquired over a 6 minutes period (18 samples). Figure 21 shows the small tri-axial isotropic probe and broadband antenna during measurements.

Fig. 21 Small probe for measuring tri-axial isotropic electric fields (rear) and broadband antenna (front)

4.1.2 Measurement sites

Strength of the surrounding electromagnetic field was targeted for measurements at a base station for 3rd generation mobile phones (W-CDMA) and 3.9th/4th generation mobile phones (LTE/4G) (one location) in Tokyo. Measurements were taken for all frequency bands and communication methods operated at the base stations to be measured (Table 2). Measurements were taken indoors.

At each site, measurements were taken by attaching the electric field probe or antenna to a non-metallic pole, at a position 1.5 m above the floor surface.

4.2 Results

Figure 22 shows measurement results for all six combinations of carrier frequencies and modulation methods listed in Table 2. The figure also shows the maximum electric field strength estimated value based on control

Table 2 Frequency bands and modulation methods operated in mobile phone base stations to be measured

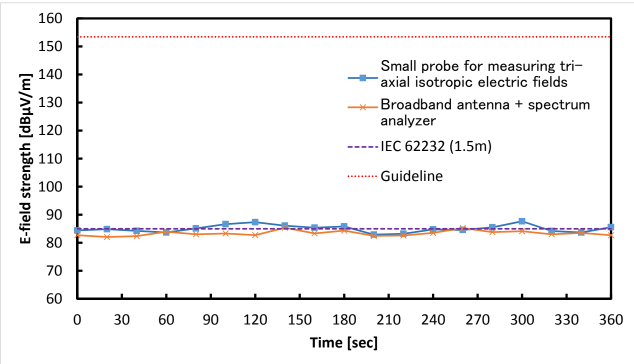
700 MHz band	800 MHz band	1.5GHz band	1.7GHz band	2GHz band
NA	W-CDMA LTE	LTE	LTE	W-CDMA LTE

channel measurement in conformance with the IEC international standard [4] performed at the same place, date and time, and the electric field strength guideline value (general environment) of RRPG.

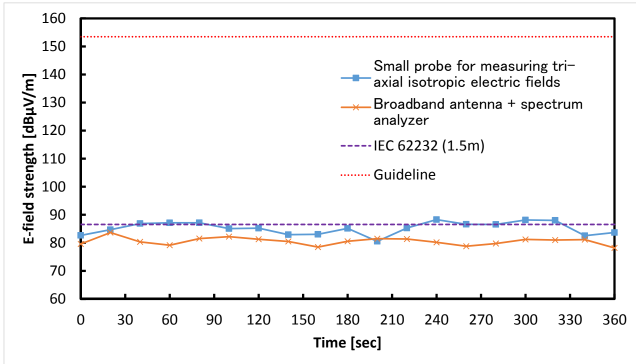
Under all conditions, fluctuations of the measured values over a 6 minutes period were around 3 to 8 dB. These measured values coincided in the range of -12 to 9 dB with respect to the maximum electric field strength based on control channel measurement in compliance with the IEC international standard. In addition, it is shown that these measurement levels / estimation levels are at least approximately 60 dB lower than the guidelines to protect against radio waves.

4.3 Discussion

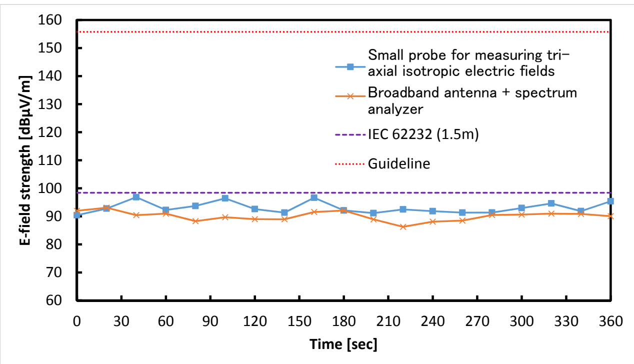
In this study, electric field intensities measured around base stations by a simple measuring system, which combines a commercially available small probe for measuring



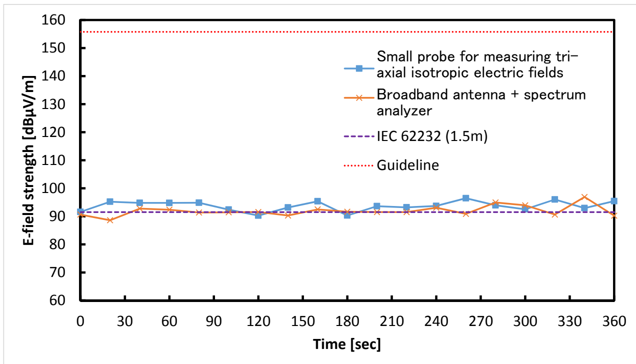
(a) 800-MHz W-CDMA



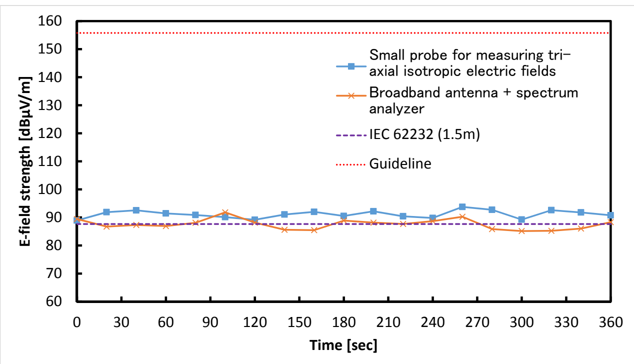
(b) 800-MHz LTE



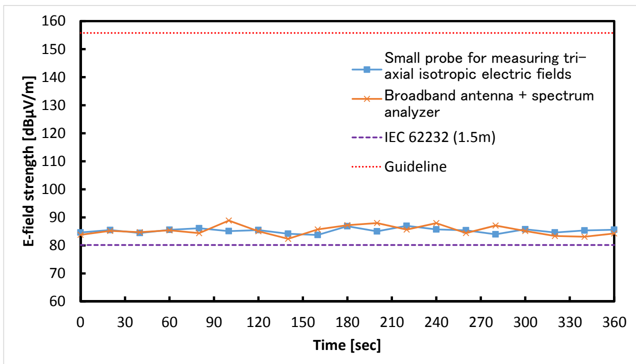
(c) 1.5-GHz LTE



(d) 1.7-GHz LTE



(e) 2-GHz LTE



(f) 2-GHz W-CDMA

Fig. 22 Measurement results of electric field strength around the base stations for 3G and 4G mobile phones (W-CDMA and LTE) (Blue line with squares: Small probe for measuring tri-axial isotropic electric fields. Orange line with ×: Broadband antenna + spectrum analyzer. Purple dashed line: Maximum electric field strength value based on control channel measurement compliant with IEC international standard [4]. Red dotted line: Electric field strength guideline value of RRPG (general environment)). Measurement locations were indoors.

tri-axial isotropic electric fields or wideband antenna and a spectrum analyzer, had sufficiently small variability (within 10 dB) relative to the margin (60 dB or more) specified in RRPG. These measurements were also within a 12 dB range of the theoretical maximum electric field strength based on control channel measurement in compliance with the IEC international standard [4]. In the previous section, it is shown that long-term traffic fluctuations over a one week period are within approximately 20 dB, and there is a possibility that larger differences may appear depending on the measurement date and time.

In addition, the simply measured values taken in this study cannot exceed the maximum electric field strength based on the control channel measurement, but we actually measured values that were overestimated up to 9 dB. This may be because, in addition to antenna calibration error and so on in the simple evaluation system, the digital modulation waveforms with strong randomness are measured by max hold, thereby showing measurement results of excessively high strength with respect to the time average value. However, in the 2 GHz band, results show that W-CDMA has simple measurement results that are more excessive than for LTE in which the Peak-to-Average Power Ratio (PAPR) value is higher, for the maximum electric field strength estimated values based on control channel measurements. Therefore, there may be a need for more detailed investigation of the causes of simplified measurement results exceeding control channel measurements.

From the above, for measurement based on simple measurements, it may be sufficient to estimate 20 dB as the effect of measurement date/time (traffic fluctuations) and so on, in addition to 12 dB, which is the difference from the theoretical maximum electric field strength evaluated in this study. Furthermore, assuming that measurements are taken at one point that is a certain height from the ground surface, the investigations up to the previous section indicate that 20 dB may be sufficient to cover the variation of the measured values due to the difference in height from the floor surface. Therefore, for the uncertainty expected for the electric field strength measurements at one location in a short time by the simple measurement system used in this study, assuming that each uncertainty factor is independent, the total uncertainty can be obtained by the sum of squares of each uncertainty; thus it can be estimated to be at most approximately 22 dB. Therefore, when there is greater margin from RRPG value, it seems possible to judge that the radio wave strength from the base station to be measured at the measurement location conforms to RRPG.

5 Conclusion

Relatively simple measurement systems comprised of a small probe for measuring tri-axial isotropic electric fields or an antenna and spectrum analyzer were used to evaluate spatial fluctuation and time variation, as uncertainty factors of electric field strength measurement around the mobile phone base stations.

The investigation of spatial variation evaluated differences in spatial average values by assigning points to them, based on electric field strength measurement data of the mobile phone base stations in five urban areas and five suburbs, from a report of the MIC [5]. For the measurements, a double rigid guide antenna and a spectrum analyzer were used. As a result, spatial average values from 3 points used in Europe and so on differed within a range of -40% to 60% compared to spatial average values from the 20 points used in Japan. There was no clear difference detected between urban areas and suburbs or 800 MHz band and 2 GHz band, regarding tendency of differences due to number of points of the spatial average. It was also shown that variation of height direction from the ground plane is within approximately 20 dB.

In the investigation of time fluctuation, radio waves from a base station for 3G mobile phones (W-CDMA) were measured over a 24 hour and one week period, using a small tri-axial isotropic probe and a broadband antenna system. As a result, in the case of the probe, differences between the time average value for 6 minutes compared to shorter time average values (10 seconds or longer) were within 0.5 dB. On the other hand, in the case of the broadband antenna system, the shorter time average values tended to increase, but it was considered to be due to problems in data processing such as very few measurement points. Additional investigation confirmed that fluctuation of the time average values basically depends on the number of samples, because W-CDMA signals fluctuate sufficiently faster than the sampling interval of the measuring devices. Also, at longer time intervals, large fluctuations (daily cycle fluctuations) of approximately 10 to 20 dB were observed.

Next, we investigated the possibility of evaluating compliance with RRPG against surrounding field strength of base stations using a simple measuring system equipped with a commercially available small probe for measuring tri-axial isotropic electric fields, broadband antenna and spectrum analyzer. Electric field strength was measured around base stations for 3G mobile phones (W-CDMA) and 4G mobile phones (LTE), and these measurements were compared against the ideal maximum electric field strength based on control channel measurement compliant with the international standard [4]. As a result, it was shown that the values measured by the simple measurement system are comparable with the ideal maximum electric field strength, within a range of 12 dB. It is shown that the total uncertainty is approximately 22 dB in consideration of the uncertainty due to spatial and temporal fluctuation investigated previously. This suggested that when there is greater margin from RRPG value, it is possible to evaluate compliance with RRPG.

Mobile phone systems continue to develop, and recently seems necessary to investigate measurement of electromagnetic field strength from base stations that operate CA, TD-LTE systems, MIMO methods and so on, for which services have started in Japan.

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Soichi WATANABE, Dr. Eng.

Research manager, Electromagnetic Compatibility Laboratory, Applied Electromagnetic Research Institute
Bioelectromagnetics

Lira HAMADA, Dr. Eng.

Senior Researcher, Electromagnetic Compatibility Laboratory, Applied Electromagnetic Research Institute
Bioelectromagnetics