Measurement of RF-EMF levels around 5G Mobile Phone Base Stations

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1. Introduction

Radiofrequency electromagnetic field (RF-EMF) used by broadcasting systems, mobile phone systems including the fifth-generation mobile communication system (5G), wireless LAN equipment, etc. that are used all around us is applied within a range that does not adversely affect the human body based on the Radio Protection Guidelines[1]. However, RF-EMF, though omnipresent in our world, are nevertheless invisible, and since new technologies and frequency bands are being used in 5G, some people are voicing concerns about RF-EMF exposure not only overseas but in Japan as well. Against this background, information on mobile phone base-station antennas and results of EMF exposure level monitoring have been released overseas on websites and elsewhere[2–4]. Furthermore, in Europe, two projects were launched in 2022 as part of Horizon Europe[5] research funding programs: SEAWave (Scientific-Based Exposure and Risk Assessment of Radiofrequency and mm-Wave Systems from children to elderly (5G and Beyond))[6] and GOLIAT (5G expOsure, causaL effects, and rIsk perception through citizen engAgemenT)[7]. Each of these projects is divided into several work packages reflecting research in EMF exposure monitoring, risk communication, etc.

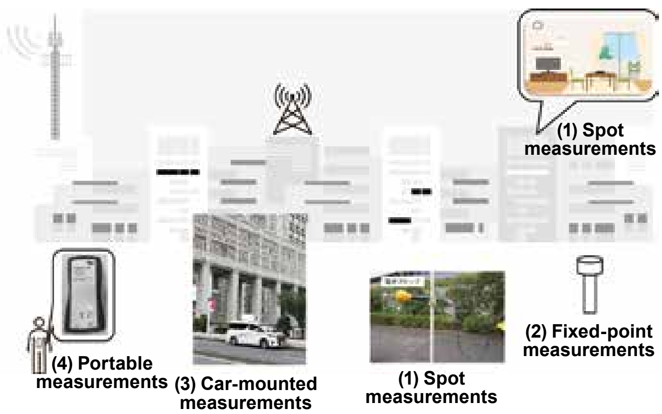
Meanwhile, in Japan, the "Strategic Research Study Group on Biological Electromagnetic Environments" of the Ministry of Internal Affairs and Communications (MIC) studied ways of conducting medium- to long-term research on the safety of EMF exposure and compiled a report in 2018 containing specific research directions for each research technique and a medium- to long-term roadmap up to 2040.[8]. In relation to research on risk communication, this report called for comprehensive measurements of EMF levels from diverse sources, long-term accumulation of that data, and widespread sharing of information on EMF exposure levels. In response to these needs, the National Institute of Information and Communications Technology (NICT) began research in FY2019 on the acquisition, accumulation, and application of EMF exposure monitoring data as Japan's only public research organization specializing in the field of information and communications. The purpose of this research was mainly to clarify fully the EMF environment in our daily lives and to present ways of risk communication to enable appropriate explanations and conversation on potential risks as the use of EMF further develops and expands[9].

At NICT, we have been making measurements outdoors or in underground shopping malls of EMF from mobile phone base stations, outdoor measurements of EMF from broadcast transmitting stations, and measurements of EMF from mobile phone base stations, terminals, and broadcast transmitting stations inside residences and classrooms. Among these, this article introduces the results of measuring EMF exposure levels around 5G mobile phone base stations.

2. Overview of measurements

Monitoring techniques for obtaining a comprehensive understanding of EMF exposure levels in real-world environments can be broadly divided into (1) spot measurements, (2) fixed-point measurements, (3) car-mounted measurements, and (4) portable measurements as shown in Figure 1. (1) Spot measurements refer to temporary measurements that can be performed at any measurement point. While they enable flexible measurement conditions to be set, they are limitations in terms of a broad range of measurements due to constraints in human resources. (2) Fixed-point measurements, meanwhile, are able to determine trends in the temporal change of EMF exposure levels by fixing a location and performing continuous, long-term measurements. Next, (3) car-mounted measurements mean performing measurements while driving a vehicle mounted with measuring equipment. As such, this technique cannot obtain temporal changes in EMF exposure levels at individual points, but it is capable of efficiently determining a spatial distribution of EMF over a wide range. Finally, (4) portable measurements refer to a technique whereby an individual performs measurements while carrying around a small measuring device. In this way, an individual can continuously

Figure 1: Overview of monitoring techniques[9]



observe actual levels of personal EMF exposure. This type of measurement is called a "microenvironment measurement." Each of the above techniques has its features and limitations, but using them in a combined and complementary manner can suppress bias in the data and enable the acquisition of large-scale and detailed EMF exposure level data.

In the early stage of 5G introduction, there was practically no EMF exposure level data with respect to 5G in real-world environments. Consequently, as described here, we performed spot measurements in the latter half of FY2022 with the aim of understanding in detail EMF exposure levels around 5G mobile phone base stations. The frequency bands targeted by these measurements are listed in Table 1. Since 5G adopts the Time Division Duplex (TDD) system, it uses the same frequency band in transmissions from a mobile phone terminal to a base station (uplink) and in transmissions from a base station to a terminal (downlink). This makes it difficult to clearly distinguish uplink and downlink signals, but since there is a high proportion of downlink signals in the frequency band of a TDD system, measurement results were evaluated as radio signals transmitted from a mobile phone base station. In recent years, moreover, frequency bands that had so far been allocated to the existing fourth-generation mobile communication system (4G) came to be approved for use by the 5G system[10] and some of them are already in operation. This article, however, targets the newly allocated 3.7 GHz and 4.5 GHz bands in Frequency Range 1 (FR1) and 28 GHz band in Frequency Range 2 (FR2) as frequency bands that better reflect the unique characteristics of 5G (Table 1). For the 28 GHz band, in particular, there are almost no examples of actual measurements even from an international perspective, so the results of the measurements presented here should be especially significant as base data for future studies.

For measurements in each of the FR1 and FR2 bands, we targeted RF-EMF levels around commercially operated base stations and performed these measurements at 51 points in Tokyo and its suburbs[11] and at 3 locations in central Tokyo[12]. For FR2, there was only a limited number of such base stations in operation at the time of these measurements, so we performed the measurements at 5 different points around each base station. For the FR1 measurements, we used a spectrum analyzer (Anritsu MS2090A) and a tri-axis isotropic antenna (Anritsu 2000-1791-R) that can be used up to 6 GHz, and for the FR2 measurements, we used an antenna supporting the 28 GHz band instead of the tri-axis isotropic antenna[12]. Additionally, to realistically evaluate RF-EMF levels around base stations in actual communication environments, we measured electric field (E-field) strength while downloading to a mobile phone terminal 6.6 GB and 10 GB of data in FR1 and FR2, respectively. Furthermore, though there were also transmissions from the terminal to the base station (uplink) during a download, we made an effort to evaluate as many downlink signals as possible from the base station so as to minimize the effects of those uplink signals on measurement results.

Moreover, to minimize effects of the measurer's body, we fixed the electric field probe or antenna to a jig made of fiber reinforced plastics (FRP) and connected the spectrum analyzer by cable. In FR2 measurements, we scanned in the vertical direction at each measurement point to make measurements at specific heights (see Figures 2 and 3) in compliance with MIC's Bulletin No. 300[13] of 1999. Specifically, we moved the antenna from a ground height of 0.1 m to 2 m at intervals of 0.1 m and measured E-field strength at each height, and at maximum height, we performed a measurement continuously for a period of one minute. On the other hand, we set the FR1 measurement height to 1.5 m based on Ref.[14]. Here, taking the resolution bandwidth (RBW) and video bandwidth (VBW) to be 1 MHz and 3 MHz, respectively, we

Table 1: Target frequencies

Name	Frequency Band [GHz]
3.7 GHz band (FR1)	3.6–4.1
4.5 GHz band (FR1)	4.5–4.6
28 GHz band (FR2)	27.0–29.5

Figure 2: Measurement overview

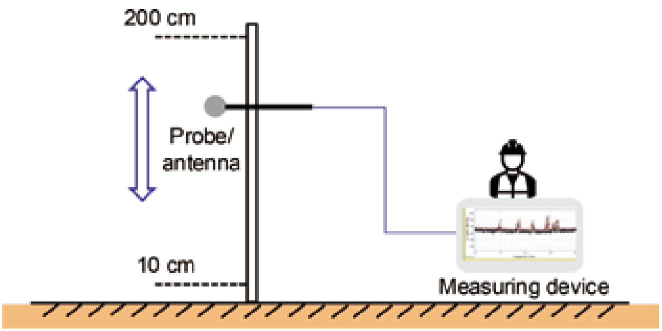
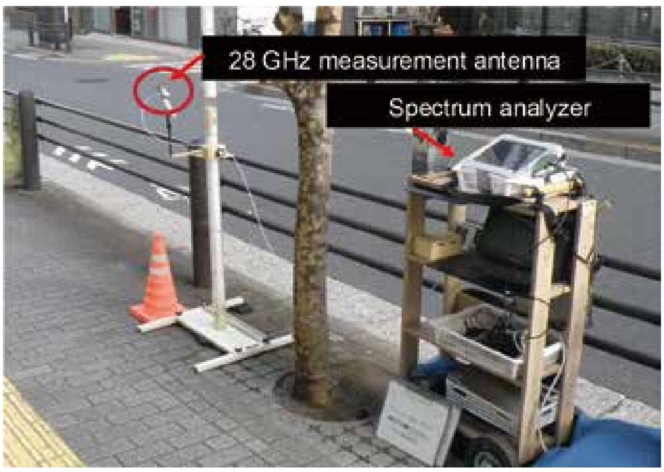


Figure 3: FR2 measurement scene[15]

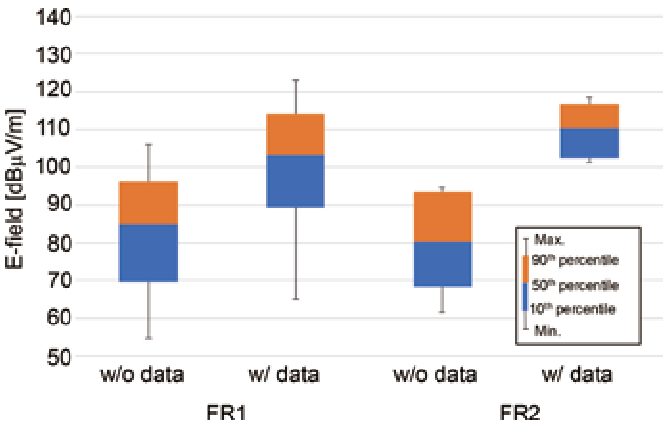


calculated the effective square root of the sum of squares of E-field strength in each band[12]. On making these calculations for each band, we excluded any values under a previously set threshold (noise floor).

3. Measurement results

Measurement results for FR1 and FR2 E-field strength [dBμV/m] are shown in Figure 4 in the form of a box and whisker plot. Here, 120 dBμV/m corresponds to 1 V/m. In the figure, "w/data" denotes that measurements were performed while downloading data to a mobile phone terminal placed near the measuring device, while "w/o data" denotes measurements without any downloading. Under the w/data condition, results showed that the median value of E-field strength tended to be 20–30 dB higher than that of w/o data. In the 28 GHz band, results for w/data showed that the median value of E-field strength was approximately 7 dB greater than that in the sub-6 GHz bands with a statistically significant difference (t-test $p < 0.0001$). On the other hand, the E-field strength value prescribed in Radio Protection Guidelines for each 5G frequency band (FR1, FR2) is 155.76 dBμV/m (61.4 V/m)[1], so it can be seen that the median value of measured E-field strength is more than 40 dB lower than the guideline value (less than 1/10,000). In addition, the 5G E-field strength measured here was found to be equivalent to or lower than that of 4G measurement results[11, 12].

Figure 4: E-field strength around 5G base stations[11, 12]



4. Conclusion

This article introduced the results of measuring base station EMF levels in a 5G mobile communication system under commercial operation in Japan. Up to now, while some examples of 5G-related measurements could be found here and there, these results represent the world's first case of measuring and announcing EMF strength around 5G FR2 base stations in commercial service by a public research organization from a neutral position.

On making these measurements for the two frequency bands used by 5G (sub-6 GHz and 28 GHz bands), it was found that E-field strength was at a level equivalent to or lower than that of the existing mobile phone system (4G) and lower than the recommended value in Radio Protection Guidelines. Going forward, with a view to the further penetration of 5G, NICT plans to achieve a long-term and large-scale understanding and data acquisition of EMF exposure levels in real-world environments in Japan through long-term fixed-point measurements, wide-area monitoring, etc.

Acknowledgments

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